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Celal N. Kostem

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LATERAL DEFLECTION PREDICTION

OF

CONCRETE FRAME-SHEAR WALL SYSTEM

by

John Brun

Celal N. Kostem

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Fritz Engineering Laboratory

Department of Civil Engineering

Lehigh University

Bethlehem, Pennsylvania

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ABSTRACT

The first part of this study focuses on the development of a mathematical model describing the drift response of a frame-shear wall structural system. The model chosen utilizes a polynomial form derived from a single variable regression analysis of data obtained by finite element analyses of several frame-shear wall structures of varying parameters. The proposed model should reduce the multi-step calculations of other approximate methods involved in estimating the structural system's response before final shear wall dimensions are used in a structural analysis program.

The second portion of the investigation examines development of a mathematical model to predict the deflection profile of the frame-shear wall structural system. The model is a polynomial form derived from a multi-variable regression analysis, which utilizes coordinate functions to describe each of the variables involved.

This information can be utilized in the modal shape analysis methods which require an initial deflected shape as input for the evaluation process. The data base for the study is the same as that utilized in part one.

Chapter 1

INTRODUCTION

As building height increases, the problem of the structure's capability to resist lateral forces becomes a concern for the structural engineer. Over the past decade, concepts have evolved to economically provide resistance to lateral forces due to wind and, in many cases, due to earthquake. These types of structural systems are shown in Fig. 1.

The interdependency of lateral force versus building height versus building rigidity becomes apparent in the design process. Traditionally, frame action usually provides sufficient lateral resistance, but when sway due to wind controls the design, the rigidity of the frame may not be adequate. Introduction of shear walls to interact with the frame improves the structures resistance of lateral loads. The shear wall's primary function is to increase the total lateral rigidity of the structure, since stiffness, and not strength, is paramount.

Basically, the frame deflects in a shear mode analogous to that of a fixed-ended beam subjected to support settlement (Fig. 2). The shear wall deflects in a bending mode similar to that of a cantilever beam (Fig. 3). When the two interact, their compatability requirement causes the deflection of the wall and the frame to be identical. To force the walls and the frame into the same deflected shape requires the generation of internal forces which equalize the deflected shape of each. Thus, the frame pulls the wall back in the upper stories and the wall pushes the frame back in the lower stories. These internal interactive forces are shown in Fig. 4.

The internal forces greatly reduce the deflection of the combined systems. This creates a stiffness considerably higher than the sum of the individual components with each resisting a portion of the exterior load. The frame-shear wall system also reduces the shear deflections of the columns. Thus, the great advantage of the system lies with the distinct feature of increasing lateral stiffness through a set of internal interactive forces.

When substantial lateral forces exist and frame-shear wall interaction is taken into account, a more economical design may be realized. The end result of the use of the shear wall is the elimination of the need to employ a very heavy frame. In short, a more balanced design is obtained. Consideration of shear wall-frame interaction leads to the reduction of shear wall moments. In most cases, the frame can accept additional moments due to lateral loading within the 33% increase in allowable stresses (Ref. 1).

1.1 Problem Statement

The type of structural system investigated here is the frame-shear wall system. Interest is focused on the application of the system to mid-height buildings.

Due to the complex nature of the building system's behavior, the analysis portion is complicated and time consuming. Chapter 2, Sections 2.1 through 2.3 describe these analysis processes in more detail.

Basically, a shortage of analysis techniques which may be employed at the preliminary dimensioning stage exists. These methods should involve minimal computational effort to describe the frame-shear wall behavior. Such a proposed simplified method would be useful in design to reduce the number of trials required to achieve an acceptable solution before actual shear wall dimensions are used in a computer analysis.

Chapter 2

FRAME-SHEAR WALL SYSTEM

2.1 Analysis and Design

Shear wall frame structures have been investigated, designed and built over the past decades. The nature of the frame-shear wall structure is complex and requires an elasticity formulation for deep shear walls while simultaneously employing matrix structural analysis for the frame portion. The simultaneous execution of these two operations is due to the structural interaction of this type building system.

While the interaction mechanism is well understood, it is the analysis portion that is the most time consuming. In the past, many simplifications and assumptions were used (Ref. 1, 6), but computerization and the advent of finite elements have gradually phased out the approximate methods (Ref. 1).

The frame-shear wall design process can be divided into four parts (Ref. 5). The first is the conceptual stage when different criteria are established from architectural and planning requirements; from this information a tentative decision is made about the location and approximate dimensions of the shear walls. The second is the analysis which determines forces acting on each of the elements. Third, stresses are checked and modifications are made to comply with the strength and code requirements. Finally, detailed design computations and plans are finalized.

2.2 Selection of Shear Wall Dimensions

Shear walls are sized by relying on an individual's engineering judgement and other information obtained from a previously designed similar structure. This approach is empirical, at best, and requires further analysis in order to evaluate the structural system's performance.

Over the past two decades semi-empirical or approximate approaches to analyze frame-shear wall systems have evolved. Table 1 lists these methods with a brief description of the type of calculations associated with each analysis method. Examination of the analysis techniques presented in Table 1 reveal that a great deal of computational effort is necessary to achieve a satisfactory result.

2.3 Approximate Methods to Check Shear Wall Adequacy

As stated in Section 2.2, numerous methods to analyze frame-shear wall structures exist. Some such methods require graphs and charts as well as accompanying computations. Therefore, only several representative methods shall be described in the following paragraphs.

In order to check the adequacy of the frame-shear wall systems, Khan and Sbarounis (Ref. 11) have prepared charts, which conceptually reduce the structure to a single frame and shear wall. Then, the stiffness ratio of the shear wall to column was computed and a corresponding chart was entered for the type of lateral loading, such as uniform or triangular. The graph shows the percentage of base shear forces which are resisted by the frame at every level and can be translated into actual forces on the equivalent frame (Fig. 5).

Another method from the same authors computes a family of deflected shapes for the interactive system given various stiffness ratios between shear wall and column for different lateral load configurations (Fig. 6). From the known deflected shape, the forces associated with the configuration may be computed.

Last is a method published by MacLeod (Ref. 12) is known as the component stiffness method. The component stiffness method has more flexibility than the Khan and Sbarounis charts, but lacks accuracy if the wall is more flexible than the frame. The main assumption is that the frame takes constant shear. Because of this assumption, the frame shear wall interaction is represented by a concentrated force at the top of the structure (Fig. 7). Essentially, this point load is nothing more than a spring of a certain stiffness (K_f). From this and other stiffness parameters defined, an equation is derived which relates P (the interaction force at the top) to W (the total applied load). Fig. 8 shows all pertinent parameters as well as equations for specific loading conditions.

As can be seen, these methods above as well as those tabulated in Table 1 require multi-step procedures or intermediate calculations of some sort in order to apply these techniques to a particular problem.

2.4 Scope of the Investigation

The effect of substantial lateral forces, such as seismic and wind, on a structure does affect its cost. Fig. 9 (Ref. 2) illustrates the effect of lateral wind loads on structural cost. Therefore, determining the effectiveness of a particular shear wall prior to a detailed computer analysis is one of the many problems facing the engineer in the design process. The performance of shear wall affects drift, lateral load resistance capacity and stability of the frame-shear wall system.

Drift criteria are used to limit a structure's deflection so that undesirable serviceability affects can be prevented as well as any instability arising from P-Δ effects. Fig. 10 illustrates the lateral deflection limitations for tall buildings (Ref. 5). Therefore, the effectiveness of the frame-shear wall systems is based on how well the system limits drift or tip deflection in accordance with prescribed limitations.

The efforts of the first part of this study focus on finding a functional relationship between the design parameters and the tip deflection of the structure. The approach taken requires application of numerical methods to develop a mathematical expression to describe this behavior. The advantage lies in streamlining the computational effort involved as opposed to existing approximate methods.

The second phase of this study involves the formulation of a general equation to predict the horizontal deflection profile of the frame-shear wall structure. The deflection profile can be used within the framework of the analysis schemes utilized by various codes such as SEAOC, UBC, and ATC-3 (Refs. 7, 8, 9).

The implementation of the results of these methodologies should be useful to the designer in reducing the number of trials required to achieve a final solution, thus, achieving economy in man hours as well as computer time.

2.5 Solution Methodology

Because of the complex nature of the frame-shear wall system, efforts of the first part of the investigation is to evaluate this building system in terms of drift criteria. Attention focuses on development of a mathematical model to evaluate the problem rather than utilizing multi-step calculations.

In order to develop this equation, the following basic steps are employed:

1. Samples of representative structures were obtained
2. A 2-D structural configuration was predetermined

3. Location of the shear wall was predetermined

4. The structures were analyzed

5. The raw data obtained in the analysis was reduced

6. Numerical methods to evaluate the raw data were applied

7. A simple mathematical expression best describing the results was developed

The basic steps listed above are performed and described in more detail in the following chapters until the final goal of producing a reliable mathematical model is reached.

2.6 Summary of Activities and Objectives

Developing a model describing the drift response of the frame-shear wall system is to simplify calculations associated with the system's performance. In order to do this, data must be obtained and examined. Data evaluation observes the effects of the variation of a select few design parameters on the structural response of the building system. Finally, a mathematical expression which best represents the results can be obtained.

The second portion of the study utilizes the data obtained from part one and applies numerical techniques to develop an expression to predict the deflection profile. This is applicable to analysis techniques used to evaluate the dynamic performance of structures.

The numerical methods employed in this investigation are based on statistical concepts. These concepts, properly applied, approximate, by some simple or complex mathematical form, the relationship between a select few variables decided upon once the raw data is reduced and examined.

Chapter 3

ANALYSIS OF FRAME-SHEAR WALL SYSTEMS USED TO FORM THE DATA BASE

3.1 Description of the Data

Three reinforced concrete, three-bay frames linked to different size shear walls provided the data for this investigation. The shear walls vary in thickness and length, but are attached to the reinforced concrete frames in only one configuraton. This frame-shear wall configuration was not varied throughout the study.

3.2 Description of the Frames

One of the three frames investigated is a three-bay eight-story frame described in the Portland Cement Association's "Analysis of Plan Multistory Frame-Shear Wall Structures Under Lateral and Gravity Loads" (Ref. 19). This frame is referred to here as Frame 1R. The dimensions and design loads for this frame are shown in Table 2 and member sizes are shown in Fig. 11.

The second frame is a three-bay, ten-story frame described by Zagajeksi and Bertero in their research program and recorded in "Computer-Aided Optimum Seismic Design of Ductile Reinforced-Concrete Moment-Resisting Frames" (Ref. 20). The frame is referred to here Frame 2R. The pertinent dimensions and working loads are shown in Table 2, and member sizes are shown in Fig. 12.

The third frame is a three-bay, twenty-story frame taken from the report by Clough and Benuska, "FHA Study of Seismic Design Criteria for High-Rise Buildings" (Ref. 21). The frame is referred to here as Frame 3R. The working loads, dimensions, and member sizes are shown in Table 2 and Fig. 13.

All three rigid concrete frames are designed to carry dead and live loads according to specifications applicable at the time of design. Frames 2R and 3R are designed not only for dead and live loads, but also for earthquake loads. The resistance to lateral forces for each frame depends entirely upon the rigidity of the member connections.

3.3 Frame-Shear Wall Configuration

Frames 1R, 2R and 3R are each linked to five different shear walls of varying dimensions. Only one type of frame-shear wall configuration is utilized throughout this study. In this arrangement the shear wall is placed adjacent to the last column line, the concrete columns are removed and full moment resisting beam-shear wall connection is assumed. This takes the three-bay reinforced concrete frame and converts it to a quasi- four-bay structural system (Fig. 14).

The configuration used is known as TYPE B, and is taken from the report by Areiza and Kostem, "Interaction of Reinforced Concrete Frame-Shear Wall Systems Subjected to Earthquake Loading" (Ref. 22).

3.4 Analysis

Each frame-shear wall structure is analyzed with TYPE B configuration using finite element computer program SAP IV (Ref. 23). The frame-shear wall models are analyzed using different shear wall dimensions, which are listed as follows:

Frame 1R - Shear Wall	Dimensions (inches)
A	10 X 72
B	10 X 96
C	10 X 120
D	10 X 144
E	10 X 168

Frame 2R - Shear Wall	Dimensions (inches)
A	12 X 96
B	12 X 120
C	12 X 144
D	12 X 168
E	12 X 192

Frame 3R - Shear Wall	Dimensions (inches)
A	16 X 144
B	16 X 168
C	16 X 192
D	16 X 216
E	16 X 240

All the frame-shear wall structures are analyzed for wind, dead and live loads. The analysis for wind, dead and live loads are considered and combined using the recommendations of the 1977 Edition of the American Concrete Institute Standards (Ref. 24). For wind load analysis, equivalent horizontal static forces acting at each floor level are computed. The study included the following six load cases:

CASE 1: Dead load only
CASE 2: Factored dead load and live load
CASE 3: Dead load and wind load
CASE 4: Factored dead load and wind load
CASE 5: Factored dead, live and wind loads
CASE 6: Wind load only

3.5 Material Properties

The concrete beams in all frames have a 28 day cylinder compressive strength 3000 psi, while the compressive strength of concrete for columns and shear walls is assumed to be 4000 psi strength. The modulus of elasticity for beams, columns, and shear walls is computed using the following formula from the 1977 ACI Code Section 8.5.1, $E_c = 57000 \sqrt{f'_c}$. Therefore, the modulus of elasticity for the beams is 3,122,019 psi, while the columns and shearwalls have an E_c value of 3,604,997 psi. Poisson's ratio for concrete is taken as .15.

3.6 Modeling Assumptions

It is assumed that the structural system is fully linear elastic in all cases. Further assumptions are as follows:

1. Structural system is planar and remains planar during the loading, which is in the plane of the structural system.

2. Beams and columns can be simulated by beam-column elements, having flexural, shear and axial deformation capabilities.

3. Shear wall is monolithic and can be described by plane stress elements.

4. All beam-to-column and beam-to-shear wall connections are rigid, i.e. have moment connections.

5. Column to foundation, as well as shear wall to foundation connections, are rigid, i.e. have non-yielding supports.

6. The contribution of the floor stiffnesses is neglected.

7. Secondary effects, such as P-Δ effects, are not included.

A typical discretized model of the frame-shear wall configuration used throughout this investigation is shown in Fig. 15.

Chapter 4

RESULTS OF THE FINITE ELEMENT ANALYSIS

4.1 Summary of the Data Preparation

In order to proceed with the development of the mathematical expression for frame-shear wall drift performance, three frame-shear wall models were analyzed with varying size shear walls in order to obtain the data base required. Once the data base is prepared, numerical techniques are employed to develop the mathematical model which best describes the data at hand.

A two-dimensional finite element analysis was performed on all the frame-shear wall models. Six load cases for each model were analyzed, but the values of load case number six (wind load only) were used in the compilation of data base. The analysis yielded results presented in both tabular and graphical form. Tabular form of the finite element results are found in Tables 3 through 6. Graphic representations are in Figures 16 through 19.

4.2 Data Evaluation

From a cursory scan of the data it became apparent that Frame 1R with shear wall was more flexible than either Frames 2R or 3R with their shear walls. The basic reason for the difference in flexibility of Frames 2R and 3R can be determined from a prior statement made in Section 2.2. This section states Frames 2R and 3R were designed for earthquake loads. This fact would account for the increased stiffness in both structures. Therefore, the resulting deflections of such structures are much less than if they were designed for dead, live and wind loads only.

4.3 Resulting Data

Frames 2R and 3R exhibit a greater lateral stiffness than Frame 1R due to their additional design for earthquake loads. This fact, coupled with the addition of the shear wall makes these structures even more laterally stiff than Frame 1R. This disparity could have some affect on the utilization of the data to determine the mathematical model for tip deflection prediction. Therefore, Frame 1R's deflection values should be similar in magnitude or compatible with those results exhibited by the other structures.

A way to compensate for the flexibility of Frame 1R is by developing a (wind load/earthquake load) ratio. A ratio was computed for each floor of the building. Once the ratios were known, they were applied to the Frame 1R model to reduce the wind load values used in the finite element analysis. Another analysis was performed with the reduced values. This caused the deflection values of the frame to be within the range of compatibility with the other frames. Both the original and modified deflection values of Frame 1R are presented in Table 4 and Figure 17.

Chapter 5

TIP DEFLECTION PREDICTION

5.1 Summary of Objectives

Control of a structure's lateral deflection (drift) is a paramount concern for the structural engineer. Not only does drift affect a structure's serviceability, but also human comfort.

It is the objective of this portion of the investigation to attempt to develop a less tedious method of estimating lateral deflection, thus providing the capability of gaging the effectiveness of one or more frame-shear wall configurations before actual dimensions are used in a computer analysis of the structure.

Since the problem has been defined and a data base created, the next steps are to define the variables associated with the problem, and to examine the data to determine the type of mathematical model to use.

5.2 Description of Analysis

Within the framework of the investigation certain data was obtained from several finite element analyses of the three frame-shear wall models. Examination of the data showed the relationship between the variables and their effect on tip deflection (drift) of the structure. From these results and utilization of statistical techniques a mathematical model best describing the data was obtained.

Since a relationship was found to exist between two (or more) variables, it is now desirable to express this relationship in a mathematical form by determining an equation relating the variables.

It is assumed that a polynomial model best represents the data obtained. The next step is to apply regression analysis technique to obtain the coefficient terms of the polynomial function. The technique is based on the method of least squares. A more detailed explanation of terms utilized can be found in any of the following references. (Refs. 25, 26).

5.3 Definition of Variables

Due to the complex nature of frame-shear wall interaction different design dimensions and/or parameters can be used as independent variables in quantification of lateral deflection characteristics. The basic dimensions considered as variables are listed below.

1. Total height of structure
2. Length of shear wall
3. Thickness of shear wall
4. Location of shear wall

Other parameters which can be considered as variables are as follows:

1. Stiffness of frame
2. Stiffness of shear wall
3. Shear area of shear Wall
4. Type of lateral loading
   a. Wind load
   b. Earthquake
5. Distribution of wind load

a. Uniform
b. Triangular
c. Parabolic
d. Stepped

Some of the variables (parameters) had already been fixed at the outset of the investigation. The only type of lateral loading considered is wind load, and as for its distribution, the assumption is that of a uniform distribution along the face of the structure. With these eliminations the next step is to determine which of those remaining independent variables has the strongest influence on tip deflection.

5.4 Determination of the Independent Variable

From prior discussion, it is evident that tip deflection (drift) is the dependent variable (Y), and is strongly influenced by one or more of the variables listed in the previous section. It is assumed, until the examination of the data, that only one independent variable will be the dominant influence; otherwise, instead of a single variable regression problem, a multi-variable regression problem exists.

The data base incorporates varying building heights, shear wall lengths and thicknesses. The construction of scatter diagrams for each variable will determine if a strong relationship exists between one of the variables and tip deflection.

Numerous combinations were tried, but yielded poor results. Some of the combinations are listed below and numbers three and four are shown in Figures 20 and 21. The remaining are listed in Appendix A.

1. Deflection vs. building height
2. Deflection vs. shear wall thickness
3. Deflection vs. shear area of wall
4. Deflection vs. shear wall length

In another attempt to compare the deformation characteristics of the data, normalization of the values by one of the variables was considered. This process succeeded in closing the gaps which existed. The term gaps is used to denote the disparity in the magnitude of the variables plotted in the scatter diagrams. Normalization actually brought the magnitude of these values closer to one another, thus indicating a clustering of the data points was occuring as opposed to in prior plots, such as Figures 20 and 21.

Several variables were tried as the normalizing value, but the one variable (Bld. Ht.)^N seemed to show promise. Finally, the field of variables were narrowed down to two. These two variables were Tip Deflection/(Bldg. Ht.)^N [Dependent Variable] and Shear Area/(Bldg. Ht.)^N [Independent Variable]. These two variables were plotted with values of the power N ranging from 1 to 3. All trial plots are listed and shown in Appendix A.

Figures 22, 23, and 24 show the effect of varying the value N. The examination of these figures illustrates that the best clustering of points exists when N = 2. This reduction in scatter suggests that some sort of relationship does exist between the variables. The grouping of points suggested a non-linear relationship existed.

Utilizing the information obtained up to this point, the next step is to choose a mathematical model which best represents the data. In other words, develop a regression equation coupled with the appropriate coefficients obtained from the regression analysis, which can be used to predict or estimate the mean response for specific values of the independent variable.

5.5 Regression Analysis

The scatter diagram of Fig. 23 indicated a non-linear relationship of some sort exists for the set of data. Examination of the data set lead to the choice of a polynomial model to describe the relationship between the two variables. With the establishment of a polynomial function used as the regression model, the next step is to decide on the order of the model. The basic form of the polynomial model is as follows:

$$Y = B_o + B_1X + B_2X^2 + B_3X^3 + \ldots. B_nX^n$$

The order of the model examined is from degree one to degree six (X^1) to (X^9).

The two variables involved in the analysis are:

Dependent Variable	(Y's)	- $\frac{\text{Tip Deflection}}{(\text{Bldg. Ht.})^2}$
Independent Variable	(X's)	- $\frac{\text{Shear Area}}{(\text{Bldg. Ht.})^2}$

Another point to be considered in the utilization of the mathematical model are the proper units of measure associated with the variables involved. The units must be dimensionally correct to achieve the appropriate results. Normalization has non-dimensionalized the independent variable (X), since both (Shear Area) and (Bldg. Ht.) values are in units of $(\text{Length})^2$. The dependent variable (Y) has a dimensional value of (1/Length). When this value is multiplied through by $(\text{Bldg. Ht.})^2$, the final value of tip deflection is in the proper units (Length).

A statistical computer package was used to solve for the regression coefficient (B's) in the polynomial model. The statistical package used for the analysis was known as BMDP (BMPD Statistical Software, Inc.) (Ref. 28). This package was available through the Lehigh University Computing Center for the Cyber 730 system. This program provides the user with a wide variety of analytical capabilities from plots and simple data to advanced statistical techniques.

The statistical analysis program employed from the package is the polynomial regression program. The program fits and plots polynomials up to degree 15. The output for each degree of polynomial includes goodness of fit statistics in order to evaluate the model.

5.6 Regression Analysis Results

The computer program provided the regression coefficients (B's) listed in Table 7 as well as other curve fit statistics provided in Table 8. A brief explanation of each statistic is provided in the following paragraphs and more detailed information can be obtained from the following References 25, 26.

For each degree of polynomial specified, the regression coefficients, the standard error and T value for each coefficient is provided.

The R-squared value is known as the coefficient of multiple determination which is a measure of how much the regression model chosen explains the observed variation in the dependent varialbe (Y). For example, an R-squared value of .955 that 95.5% of the sample variation in X is explained through the polynomial regression equation between X and Y.

The T-statistic is basically used to construct a confidence interval for each regression coefficient (B's). The standard error value is also included for each coefficient. This particular value is used as an estimator for the standard deviation from which confidence and prediction intervals can be obtained.

Goodness of fit test for each degree of polynomial is a test made for additional information in the orthogonal polynomials of higher degree. The numerator sum of squares for each of these tests is the sum of squares attributed to all orthogonal polynomials of higher degree and the denominator sum of squares is the residual sum of squares from the fit to the highest degree polynomial. A significant F-statistic indicates that a higher degree polynomial should be considered.

All the information provided by these test statistics are combined to evaluate the effectiveness of a particular degree of polynomial model. Finally, a recommendation as to whether higher degree models are useful can be made.

The next step is to utilize the fitted regression curve to predict values for some test cases. The test cases were obtained utilizing the three basic frame-shear wall configurations and varying the shear wall lengths. The results are tabulated in Tables 9 through 11. The tables list the polynomial curve fit from order one to order six and their predicted tip deflection values and compare them with the finite element results.

5.7 Observations

Despite the fact that a polynomial model was chosen, there exists other types of approximating curves which could have been utilized. For the purpose of discussion, several types of approximating models are listed. It should be noted that letters other than X or Y represent numerical constants, while X and Y are the variables representing independent and dependent variables.

1) Straight line $Y = B_0+B_1X$

2) Polynomial $Y = B_0+B_1X+B_2X^2+B_3X^3+\ldots B_nX^n$

3) Exponential $Y = B_0B_1{}^X$

4) Hyperbolic $Y = \dfrac{1}{B_0+B_1X}$

5) Logarithmic $Y = B_0+B_1LOG(X)$

6) Geometric (Power) $Y = B_0X^{B_1}$

7) Harmonic $Y = B_0+\Sigma(B_n\cos(nx)+\alpha_n\sin(nx))$

Re-examination of the scatter diagram indicates there may be no need for the rigorous nature of the harmonic curve fit. The straight line fit is nothing more than a special case of the polynomial model which was used. Other models indicate the possibility that a better fit could be achieved with the exponential, logarithmic, geometric (power) and hyperbolic models. Any one of these approximating curves could have been used to best describe the data at hand, but various constraints made investigating each of these other models impractical at this time; therefore, these curve fits are left for future investigation.

5.8 Tip Deflection Prediction Conclusions

Examination of the R-squared values in Table 8 indicate that slight improvement in the predictive capabilities of the regression model is gained by increasing the order of the polynomial. Further examination of the F-statistics, in the same table, confirms this trend. This tendency is also strengthened by inspection of the T and standard error statistics for each regression coefficient in each degree of polynomial (Appendix B). From this information, higher order polynomials of degrees seven through nine can be eliminated; therefore, only regression coefficients of order one through six are included in Table 7.

Figures 25 through 30 show the fitted polynomial curves in relation to the raw data points. Examination of these curves also shows no real significant changes in the curves for polynomials degree four through six. For the purposes of discussion, lower order polynomials are defined as degree one through six,while higher order polynomials are defined as degree four through six.

Focusing attention on the test cases Tables 9 through 11 shows the following observations to be noteworthy. The eight-story structure's tip deflection, for shear area values greater than 1000 in^2, are best predicted using lower order polynomials (uper bound solution), with degree one being the most accurate. The ten-story structure shows that for shear area's between 1200 in^2 and 2000 in^2 lower order polynomials once again yield good results (upper bound solution), with the third degree polynomial being the most accurate. The twenty-story structure indicates that for shear areas between 2880 in^2 and 3600 in^2 lower degree polynomials fair well at predicting tip deflection values (upper bound solution), with degree three being the most accurate. Lower bound solutions result using high or low order polynomials for the eight-story structure with shear areas less than 1000 in^2, ten-story structure with shear areas greater than 2000 in^2, and lastly in the twenty story structure for shear areas lss than 2800 in^2.

For all three structures, the tip deflection results utilizing lower order polynomials are much better than utilizing higher order polynomials. The engineering reasonableness of such higher degree polynomials is debatable. With higher order terms the curve can be forced to conform to the data points; therefore, according to the principle of least squares, a degree of polynomial can be found which fits all the data points so that minimization of error is essentially zero. However, in virtually most applications of the polynomial model, having a large number of terms is quite unrealistic (Ref. 25). In most engineering applications, a quadratic or cubic is appropriate; therefore, the use of lower order polynomials is more acceptable for engineering interpretations over higher order terms. This trend can be seen by examining the regression statistics from the computer program as well as by inspecting the test case values. All show lower order polynomials more acceptable.

In conclusion, the following trends have been noted during the first portion of the study.

1. The structures used in the compilation of the data base should have similar stiffness characteristics in order to achieve reasonable results.

2. Selection of the degree of equation for tip deflection prediction of the frame-shear wall system is dependent upon the structure's height and range of shear area values.

3. Lower order polynomials provide an upper bound solution for most ranges of shear areas and building height values.

4. Based on information from the computer program the degree of model should not really go beyond a cubic for this particular data set.

5. Lower order polynomials are more acceptable for engineering interpretations.

Chapter 6

DEFLECTION PROFILE PREDICTION

6.1 Summary of Objectives

This portion of the investigation attempts to develop a mathematical model to predict the deflection profile for the frame-shear wall system. The model was determined utilizing regression analysis techniques from the data base developed in Chapter 3 of this report. The deflection profile can be used within the framework of the analysis schemes utilized by the various codes such as UBC, ATC-3, and SEAOC (Refs. 7, 8, 9).

6.2 Applicability of Deflection Profile Values

Codes of standard practice relating to lateral loads due to earthquakes rely mainly on a simple static force approach in order to analyze structural response. The codes also incorporate various degrees of refinement in an attempt to simulate real structural behavior as much as possible. These guidelines also provide approximate values for various critical dynamic parameters, but all codes state that based on the properties of the seismic resisting system more exact values may be computed utilizing more established methods of analysis.

For large complex structures static methods of seismic analysis are not accurate enough and, therefore, demand a more thorough dynamic analysis. The three main techniques currently used are:

1. Direct Integration (of the equations of motion) (Step-by-step procedure)

2. Modal Analysis

3. Response Spectrum Analysis

Of the three techniques listed, Direct Integration is the most powerful but also the most expensive to carry out. Response spectrum technique is a simplified special case of modal analysis; therefore, modal analysis usually can provide the desired order of accuracy for linear behavior by incorporating all modal responses, some approximation is usually made by using only the first few modes in order to save computation time.

One of a few such modal analysis techniques is known as the Stodala Method. The method utilizes an initial assumption of the vibration mode shape, and this deflected shape is adjusted iteratively until the true mode shape is obtained. Another method relying on an assumed deflected shape is the Rayleigh-Ritz Method. At this point the ability to predict a deflection profile would be very useful rather than to assume some arbitrary deflected shape.

The deflection profile values developed by the regression model will be a far better representaton of the initial mode shape, thus enhancing these modal analysis methods by achieving a solution in a much shorter time period.

6.3 Definition of Variables

From the knowledge gained in the previous chapter about the interrelationships of variables. It is clear that the problem of predicting the deflection profile of the frame-shear wall system involves more than one independent variable. These variables were initially assumed to affect the deflected shape of the structure:

1. Shear area of wall
2. Total structure height (No. of stories)
3. Individual story height deflections

The independent variables listed above have a disparity in magnitudes; therefore, normalization of the values was again utilized so that the magnitudes of all three parameters are in the same range. The normalization process has non-dimensionalized each of the variables. Variable (1) was normalized with respect to a unit shear area. Similarly, Variable (2) was normalized with respect to a unit total story number. Variable (3) was normalized with respect to the tip deflection of the structure.

Since three independent variables are involved there is no longer a simple two-dimensional relationship between the scatter of the data points. Now a three-dimensional relationship develops where the actual scatter of points lies in space. The mathematical model used to describe these points now represents a plane; therefore, the scatter of these points should not be far from this plane known as the approximating plane. As the number of independent variables exceeds three, geometric intuition is lost since four, five or up to N-Dimensional spaces are required.

6.4 Regression Analysis

In this segment of the study a multi-variable regression analysis is employed to determine the deflection profile values as a function of the three independent variables listed in the prior section. Development of such a program was required. The basic theory utilized was that of least squares and the remaining procedures for development of the regression program were obtained from Reference 27, and modified to suit the particular problem at hand. A brief explanation of the basic concepts in the program is presented in the following paragraphs.

When there are more than one independent variables it is often advantageous to establish the effect of just one variable (i.e., j-th Variable) while all other variables are kept constant. The assembly of the K_{ij} terms are selected to make a close approximation of this function to the given data points for various sets of the other variables. The aim is to have as few terms as possible for an acceptable fit. The established coordinate function F_j for j-th variable contains n_j terms as seen in Eq. (6.1).

$$F_j = [\ k_{j1}\ k_{j2}\ \ldots\ldots\ k_{jnj}\ ] \tag{6.1}$$

With a coordinate function established for each variable the terms of the final series shown in Eq. (6.2) contains products of the terms of the individual coordinate functions.

$$S = B_j f_j = \{B_i\}^T[f_1 f_2 \ldots f_n]^T = B^T [f_1 f_2 \ldots f_n]^T \tag{6.2}$$

The final coordinate function is obtained as a direct product of the terms. This operation is represented by the following dprod (....).

$$F = [f_1 f_2 \ldots f_n] = \text{dprod } (F_1 F_2 \ldots F_n)$$

$$F = [\ (k_{11} k_{21} \ldots k_{ji})\ (k_{12} \ldots k_{j2}) \ldots (k_{1nj}\ k_{2nj} \ldots k_{jnj})\ ] \tag{6.3}$$

Thus, a change in the coordinate function of a particular variable does not affect the coordinate functions of the other variables. Finally the unknown coefficients $\{B_i\}$ are found by the solution of a set of simultaneous equations. A more detailed explanation of the methodology is given in Appendix C.

6.5 Coordinate Function Expressions for Variables

The three independent variables selected for the regression analysis each need to be defined by a coordinate function expression. The following functions describe the variables used:

Variable (1) = $(C + CS + CS^2 + CS^3)$ - Shear Area of Wall

Variable (2) = $(X + X^2 + X^3 + X^4)$ - Individual Story Height Deflections

Variable (3) = (1 + Z) - Total No. of Stories

The rationale for the choice of the above function was arbitrary for the third variable. For the first variable it was based on the curve fit of data in part one, where the tip deflection and shear area relationship was best described by a cubic relationship. The second variable's expression was arrived at by idealizing the frame-shear wall system as a fix-ended cantilever beam with a uniform load. Examination of the deflection expression for such a structure indicates third and fourth order terms are present; therefore, the fourth order polynomial expression was deemed appropriate.

6.6 Regression Analysis Results

The computer analysis provided the values listed in Tables 13 through 15. These tables compare the actual deflection values in a normalized form from the F.E.M. analysis and relates them to those values predicted by the regression equation. These results are also presented in graphical form in Figures 31 through 33, which show the comparison of F.E.M. (solid line) values to the regression results (symbols). For the sake of clarity, the graphs begin their plots at the first story instead of at the ground floor. Table 12 illustrates the expansion of terms in the equation including all the coefficient values (B's). It also was of interest to provide a shortened version of this equation using truncated coefficient values. The tabulated results for this form of the equation are presented in Tables 16 through 19.

Since the regression model contains three independent variables, a visual representation or scatter diagram becomes more difficult to interpret. Therefore, the R-squared value becomes a much more critical parameter in order to assess the effectiveness of the mathematical model. Appropriate graphical results also aid in model assessment. The program calculates the R-squared value for each particular case input as well as a plot of the normalized deflection profiles for all cases.

6.7 Deflection Profile Prediction Conclusions

Examination of the regression results indicate extremely good correlation exists. The 15 plots in the graph of Figure 34 show a relatively narrow banded result of the regression model. This banding is indicative of good agreement between actual and predicted values. Figures 31 through 33 also confirm this trend. The R-squared values are always in the neighborhood of .99. So, the model is able to explain 99% of the sample variation. Despite the form of this perhaps cumbersome 32 term equation, the results are reasonably reliable. Even the version of the equation with the truncated coefficients yields R-squared results of .90 and up. All results shown are in non-dimensionalized terms; therefore, applicable to any other system of measure. To obtain the true deflection value, one needs only to multiply by the tip deflection for the structure, since the actual values were normalized with respect to tip deflection. To obtain a tip deflection estimate, one may utilize the equations developed in Chapter 5.

It is not clear cut as to whether the model provides an upper or lower bound solution, but examination of the data would seem to indicate the trend is toward an upper bound solution. This upper bound terminology simply states that the regression model yields values equal to or slightly higher than the actual values determined from the finite element analysis.

As previously stated, the polynomial equation may be considered cumbersome in form, but since computing capabilities have improved, this mathematical expression becomes virtually simple to utilize. Once programmed into a micro-computer or hand held calculator, the equation is readily available for use.

Chapter 7

CONCLUSIONS

7.1 Summary

This report presents a methodology for use in estimating the tip deflection of a frame-shear wall structure. This method provides the estimate utilizing the shear area of the shear wall in a polynomial equation. The following conclusions are summarized from this first part of the study:

1. Structures should have similar stiffness characteristics.
2. Lower order polynomials provide an upper bound solution.
3. Degree of model used to predict tip deflection is dependent on shear area and height of structure.
4. Degree Three polynomial is more than adequate for prediction of tip deflection for this particular data set.

The second portion of the study developed a model to predict the deflection profile of the frame-shear wall structure. The model utilizes coordinate functions to describe each variable. This part of the study yielded the following results:

1. 32-term equation yields good results between the equation and F.E.M. values.
2. Narrow banded plot of predicted values indicative of good agreement in predictive capabilities.

7.2 Future Research

This investigation has just touched on the fringes of utilizing the concepts presented. Further study of these findings should include some of the following points:

1. The data base should be enlarged to include different building as well as shear wall geometrics, each utilizing wind loadings other than that of a uniformly distributed load.

2. Examine different functions other than the polynomial form in order to gain more information as to which type best describes the tip deflection data.

3. Utilize the deflection profile prediction equation in a dynamic analysis to gage its effectiveness in reducing the number of iterations required.

T A B L E S

TABLE 1

SUMMARY OF ANALYSIS METHODS
FOR
FRAME-SHEAR WALL INTERACTION

AUTHOR(S)	CALCULATIONS REQUIRED	(REFS.)
PARME	SET OF SIMULTANEOUS DIFFERENCE EQUATIONS OF ORDER EQUAL TO THE NUMBER OF STORIES; FORM EQUATION SIMPLIFIES THE SOLUTION	(REF. 14)
GOULD	SIMILAR TO THE PARME METHOD; METHOD OF SOLVING EQUATIONS IS NOT DESCRIBED	(REF. 15)
CARDIN	SUBSTITUTION INTO DIFFERENTIAL EQUATIONS; NO SIMULTANEOUS EQUATIONS OR ITERATIONS	(REF. 17)
ROSMAN	METHOD SIMILAR TO CARDIN	(REF. 18)
ROSENBLUETH & HOLTZ	SUCCESSIVE APPROXIMATIONS TO INTERACTING FORCES	(REF. 16)
KHAN & SBAROUNIS	NO SWAY MOMENT DISTRIBUTION OR SLOPE DEFLECTION ANALYSIS OF FRAME; CALCULATION OF DEFLECTION FOR FRAME AND SHEAR WALL; ITERATIVE PROCESS	(REF. 11)
McLEOD	COMBINATION OF CHART & EQUATIONS	(REF. 12)

TABLE 2

DESIGN LOADS	FRAME 1R	FRAME 2R	FRAME 3R
BENT / FRAME SPACING	25 FT.	27 FT.	25 FT.
WIND LOAD (UNIFORM DISTRIBUTION)	25 P.S.F.	25 P.S.F.	25 P.S.F.
DEAD LOADS			
ROOF	155 P.S.F.	155 P.S.F.	155 P.S.F.
TYPICAL FLOOR	145 P.S.F.	145 P.S.F.	145 P.S.F.
LIVE LOADS			
ROOF	20 P.S.F.	20 P.S.F.	20 P.S.F.
TYPICAL FLOOR	50 P.S.F.	50 P.S.F.	50 P.S.F.
MATERIAL PROPERTIES			
CONCRETE STRENGTH			
COLUMNS	4000 P.S.I.	4000 P.S.I.	4000 P.S.I.
BEAMS	3000 P.S.I.	3000 P.S.I.	3000 P.S.I.
MODULUS OF ELASTICITY			
COLUMNS	3,604,997 P.S.I.	3,604,997 P.S.I.	3,604,997 P.S.I.
BEAMS	3,122,019 P.S.I.	3,122,019 P.S.I.	3,122,019 P.S.I.

TABLE 3

DEFLECTION PROFILE DATA FRAME 1R						
SHEAR WALL THICKNESS 10 (INCHES)						
SHEAR WALL LENGTHS		6'-0 72"	8'-0 96"	10'-0 120"	12'-0 144"	14'-0 168"
SHEAR AREA		720 in^2	960 in^2	1200 in^2	1440 in^2	1680 in^2
STORY NO.	BLDG. HT.(IN.)	DEFLECTIONS (INCHES)				
8	1140	2.19	1.64	1.19	.846	.605
7	1008	1.95	1.43	1.02	.724	.516
6	876	1.69	1.21	.855	.601	.427
5	744	1.41	.981	.685	.478	.339
4	612	1.10	.749	.516	.358	.253
3	480	.790	.523	.355	.244	.173
2	348	.490	.314	.210	.144	.101
1	216	.230	.140	.093	.064	.044

TABLE 4

DEFLECTION PROFILE DATA (MODIFIED) FRAME 1R						
SHEAR WALL THICKNESS 10 (INCHES)						
SHEAR WALL LENGTHS		6'-0 72"	8'-0 96"	10'-0 120"	12'-0 144"	14'-0 168"
SHEAR AREA		720 in^2	960 in^2	1200 in^2	1440 in^2	1680 in^2
STORY NO.	BLDG. HT.(IN)	DEFLECTIONS (INCHES)				
8	1140	.480	.355	.256	.182	.130
7	1008	.435	.313	.223	.157	.112
6	876	.386	.270	.190	.133	.094
5	744	.332	.224	.155	.108	.076
4	612	.271	.178	.121	.083	.158
3	480	.204	.129	.086	.059	.041
2	348	.134	.081	.053	.036	.025
1	216	.066	.038	.025	.017	.102

TABLE 5

DEFLECTION PROFILE DATA FRAME 2R						
SHEAR WALL THICKNESS 12 (INCHES)						
SHEAR WALL LENGTHS		8'-0 96"	10'-0 120"	12'-0 144"	14'-0 168"	16'-0 192"
SHEAR AREA		1152 in^2	1440 in^2	1728 in^2	2016 in^2	2304 in^2
STORY NO.	BLDG. HT.(IN)	DEFLECTIONS (INCHES)				
10	1488	.651	.600	.545	.488	.432
9	1344	.612	.556	.598	.442	.387
8	1200	.566	.507	.448	.393	.341
7	1056	.511	.452	.394	.342	.294
6	912	.448	.390	.336	.287	.245
5	769	.376	.322	.273	.231	.196
4	624	.298	.250	.209	.174	.146
3	480	.215	.177	.145	.119	.099
2	336	.131	.105	.084	.068	.056
1	192	.054	.042	.034	.027	.022

TABLE 6

DEFLECTION PROFILE DATA FRAME 3R						
SHEAR WALL THICKNESS 16 (INCHES)						
SHEAR WALL LENGTHS		12'-0 144"	14'-0 168"	16'-0 192"	18'-0 216"	20'-0 240"
SHEAR AREA		2305 in^2	2688 in^2	3072 in^2	3456 in^2	3840 in^2
STORY NO.	BLDG. HT. (IN.)	DEFLECTIONS (INCHES)				
20	2916	4.09	3.62	3.21	2.85	2.51
19	2772	3.93	3.46	3.06	2.70	2.38
18	2628	3.77	3.30	2.90	2.55	2.24
17	2484	3.61	3.14	2.74	2.40	2.10
16	3340	3.44	2.97	2.58	2.25	1.96
15	2196	3.26	2.80	2.42	2.10	1.82
14	2052	3.08	2.62	2.25	1.94	1.68
13	1908	2.88	2.43	2.07	1.78	1.53
12	1764	2.68	2.24	1.96	1.62	1.39
11	1620	2.47	2.05	1.72	1.46	1.24
10	1476	2.26	1.85	1.54	1.29	1.10
9	1332	2.03	1.64	1.35	1.13	.954
8	1188	1.80	1.43	1.17	.968	.811
7	1044	1.56	1.22	.983	.801	.672
6	900	1.31	1.01	.800	.651	.538
5	756	1.04	.789	.619	.499	.409
4	612	.765	.571	.443	.354	.289
3	468	.496	.366	.282	.224	.182
2	324	.264	.193	.148	.117	.095
1	180	.092	.067	.052	.041	.034

TABLE 7

RESULTS OF REGRESSION COEFFICIENTS

DEG. OF POLY.	POLYNOMIAL COEFFICIENTS							
	B_0	B_1X	B_2X^2	B_3X^3	B_4X^4	B_5X^5	B_6X^6	
1	.49781E-6	-.31252E-3						
2	.53554E-6	-.43467E-3	.81891E-1					
3	.68979E-6	-.11949E-2	.11694E+1	-.46756E-3				
4	.10498E-5	-.36190E-2	.66963E+1	-.55899E+4	.16525E+7			
5	.15861E-5	-.82074E-2	.21199E+2	-.26891E+5	.16318E+8	-.3818E+10		
6	.27193E-5	.19985E-1	.69092E+2	.12474E+6	.12277E+9	-.62589E+11	.12928E+14	

VARIABLE X

$$X = \frac{\text{SHEAR AREA}}{(\text{TOTAL BLDG. HT.})^2}$$

TABLE 8

REGRESSION CURVE FIT STATISTICS			
DEG. OF POLY.	R - SQUARED VALUES		F - STATISTIC
	DECIMAL FORM	PERCENT FORM	
1	.9264	92.64%	19.71
2	.9135	93.15%	1.05
3	.9448	94.48%	1.07
4	.9554	95.54%	.83
5	.9584	95.84%	.63
6	.9600	96.00%	.65
7	.9709	97.09%	.76
8	.9718	97.18%	.16
9	.9726	97.26%	.13

TABLE 9

TEST CASES TIP DEFLECTION VALUES FRAME 1R (8 STORY STRUCTURE)										
SHEAR WALL THICKNESS 10"										
TOTAL BUILDING HEIGHT 1140"										
SHEAR WALL LENGTHS	7'-0 84"		9'-0 108"		11'-0 132"		13'-0 156"			
SHEAR AREA	840 in^2		1080 in^2		1320 in^2		1560 in^2			
DEGREE OF POLYNOMIAL	TIP DEFLECTION (INCHES)									
	Δ POLY.	Δ F.E.M.	Δ POLY.	Δ F.E.M	Δ POLY.	Δ F.E.M.	Δ POLY.	Δ F.E.M.		
1	.384	.413	.309	.302	.234	.215	.159	.153		
2	.374	.413	.300	.302	.232	.215	.171	.153		
3	.364	.413	.306	.302	.250	.215	.171	.153		
4	.373	.413	.321	.302	.238	.215	.151	.153		
5	.382	.413	.314	.302	.236	.215	.172	.153		
6	.381	.413	.314	.302	.247	.215	.151	.153		

TABLE 10

TEST CASES
TIP DEFLECTION VALUES
FRAME 2R (10 STORY STRUCTURE)

SHEAR WALL THICKNESS 12"

TOTAL BUILDING HEIGHT 1488"

SHEAR WALL LENGTHS	9'-0 108"		11'-0 132"		13'-0 156"		15'-0 180"			
SHEAR AREA	1296 in^2		1584 in^2		1872 in^2		2160 in^2			
DEGREE OF POLYNOMIAL	TIP DEFLECTION (INCHES)									
	Δ POLY.	Δ F.E.M.	Δ POLY.	Δ F.E.M.	Δ POLY.	Δ F.E.M.	Δ POLY.	Δ F.E.M.		
1	.697	.626	.607	.573	.517	.517	.427	.460		
2	.685	.626	.590	.573	.502	.517	.419	.460		
3	.658	.626	.581	.573	.516	.517	.449	.460		
4	.661	.626	.607	.573	.537	.517	.440	.460		
5	.676	.626	.613	.573	.525	.517	.430	.460		
6	.683	.626	.605	.573	.526	.517	.449	.460		

TABLE 11

TEST CASES TIP DEFLECTION VALUES FRAME 3R (20 STORY STRUCTURE)										
SHEAR WALL THICKNESS 16"										
TOTAL BUILDING HEIGHT 2916"										
SHEAR WALL LENGTHS	13'-0 156"		13'-6 162"		15'-0 180"		17'-6 210"		19'-0 228"	
SHEAR AREA	2496 in^2		2592 in^2		2880 in^2		3360 in^2		3648 in^2	
DEGREE OF POLYNOMIAL	TIP DEFLECTION (INCHES)									
	Δ POLY.	Δ F.E.M.	Δ POLY.	Δ F.E.M.	Δ POLY.	Δ F.E.M.	Δ POLY	Δ F.E.M.	Δ POLY.	Δ F.E.M.
1	3.45	3.84	3.42	3.73	3.33	3.41	3.18	2.93	3.09	2.68
2	3.52	3.84	3.49	3.73	3.38	3.41	3.20	2.93	3.09	2.68
3	3.63	3.84	3.58	3.73	3.41	3.41	3.16	2.93	3.02	2.68
4	3.70	3.84	3.61	3.73	3.37	3.41	3.07	3.93	2.93	2.68
5	3.71	3.84	3.60	3.73	3.32	3.41	3.02	2.93	2.90	2.68
6	3.70	3.84	3.57	3.73	3.28	3.41	3.01	2.93	2.91	2.68

TABLE 12

EXPANDED FORM OF THE REGRESSION EQUATION

$$
\begin{aligned}
\delta = {} & \left[(B_1 + B_2 S + B_3 S^2 + B_4 S^3) * (1) + (B_5 + B_6 S + B_7 S^2 + B_8 S^3) * (Z)\right] * X \\
+ & \left[(B_9 + B_{10} S + B_{11} S^2 + B_{12} S^3) * (1) + (B_{13} + B_{14} S + B_{15} S^2 + B_{16} S^3) * (Z)\right] * X^2 \\
+ & \left[(B_{17} + B_{18} S + B_{19} S^2 + B_{20} S^3) * (1) + (B_{21} + B_{22} S + B_{23} S^2 + B_{24} S^3) * (Z)\right] * X^3 \\
+ & \left[(B_{25} + B_{26} S + B_{27} S^2 + B_{28} S^3) * (1) + (B_{29} + B_{30} S + B_{31} S^2 + B_{32} S^3) * (Z)\right] * X^4
\end{aligned}
$$

REGRESSION COEFFICIENTS

B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8
-.415603	-2.35553	9.63049	-8.29273	2.97520	-3.91031	-4.33127	6.81431
B_9	B_{10}	B_{11}	B_{12}	B_{13}	B_{14}	B_{15}	B_{16}
-5.40671	4.59172	43.9108	-52.7253	29.8911	-84.7171	55.4532	11.5515
B_{17}	B_{18}	B_{19}	B_{20}	B_{21}	B_{22}	B_{23}	B_{24}
10.5224	3.16167	-98.2501	104.718	-53.1244	134.469	-65.3597	-38.7485
B_{25}	B_{26}	B_{27}	B_{28}	B_{29}	B_{30}	B_{31}	B_{32}
-3.69381	-5.45472	44.7800	-43.7121	20.2444	-45.6904	13.9968	20.4802

TABLE 13

DEFLECTION PROFILE VALUES (NORMALIZED) FRAME 1R (8-STORY STRUCTURE)

		STORY NUMBER							
		1	2	3	4	5	6	7	8
		NORMALIZED DEFLECTION VALUES							
SHEAR AREA 720 in^2 R^2=.999	Δ F.E.M.	.138	.279	.425	.565	.692	.804	.906	1.00
	Δ REGRESS	.138	.275	.423	.564	.693	.804	.904	1.00
SHEAR AREA 960 in^2 R^2=.999	Δ F.E.M.	.107	.228	.363	.501	.634	.761	.882	1.00
	Δ REGRESS	.113	.231	.366	.503	.637	.761	.881	1.00
SHEAR AREA 1200 in^2 R^2=1.00	Δ F.E.M.	.098	.207	.336	.473	.605	.742	.871	1.00
	Δ REGRESS	.099	.208	.336	.471	.608	.740	.870	1.00
SHEAR AREA 1440 in^2 R^2=.999	Δ F.E.M.	.093	.198	.324	.456	.593	.731	.863	1.00
	Δ REGRESS	.092	.198	.324	.460	.598	.734	.867	1.00
SHEAR AREA 1680 in^2 R^2=.999	Δ F.E.M.	.092	.192	.315	.446	.585	.723	.862	1.00
	Δ REGRESS	.090	.196	.323	.460	.600	.736	.869	.999

TABLE 14

DEFLECTION PROFILE VALUES (NORMALIZED) FRAME 2R (10-STORY STRUCTURE)											
		STORY NUMBER									
		1	2	3	4	5	6	7	8	9	10
		NORMALIZED DEFLECTION VALUES									
SHEAR AREA 1152 in^2	Δ F.E.M.	.083	.201	.330	.458	.578	.688	.785	.869	.940	1.00
R^2 =.999	Δ REGRESS.	.088	.199	.327	.457	.582	.694	.790	.869	.938	1.00
SHEAR AREA 1440 in^2	Δ F.E.M.	.070	.175	.295	.417	.537	.650	.753	.845	.927	1.00
R^2 =.999	Δ REGRESS.	.074	.170	.285	.406	.526	.639	.742	.834	.919	1.00
SHEAR AREA 1728 in^2	Δ F.E.M.	.062	.154	.266	.383	.501	.617	.723	.822	.914	1.00
R^2 =.999	Δ REGRESS.	.065	.154	.261	.377	.495	.609	.716	.815	.909	1.00
SHEAR AREA 2016 in^2	Δ F.E.M.	.055	.139	.244	.357	.473	.588	.701	.805	.906	1.00
R^2 =.999	Δ REGRESS.	.059	.142	.245	.358	.475	.590	.700	.803	.903	1.00
SHEAR AREA 2304 in^2	Δ F.E.M.	.051	.130	.229	.338	.454	.560	.681	.789	.896	1.00
R^2 =.999	Δ REGRESS.	.052	.129	.267	.335	.450	.566	.680	.789	.895	1.00

TABLE 15

DEFLECTION PROFILE VALUES (NORMALIZED) FRAME 3R (20-STORY STRUCTURE)

SHEAR AREA / R^2		STORY NUMBER: 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
		NORMALIZED DEFLECTION VALUES																			
2304	Δ F.E.M	.022	.065	.121	.187	.254	.320	.381	.440	.496	.553	.604	.655	.704	.757	.797	.841	.883	.922	.961	1.00
.999	Δ REGR.	.036	.078	.128	.187	.249	.314	.379	.442	.505	.564	.620	.672	.719	.764	.805	.844	.883	.921	.962	1.00
2688	Δ F.E.M	.019	.053	.101	.158	.218	.279	.337	.395	.453	.511	.566	.619	.671	.724	.773	.820	.867	.912	.956	1.00
.999	Δ REGR.	.027	.061	.103	.154	.208	.266	.325	.384	.445	.503	.560	.613	.665	.715	.763	.809	.856	.903	.953	1.00
3072	Δ F.E.M	.016	.046	.088	.138	.193	.249	.306	.364	.421	.480	.536	.592	.645	.701	.754	.804	.854	.903	.953	1.00
.999	Δ REGR.	.022	.051	.090	.137	.188	.244	.301	.359	.419	.478	.536	.592	.646	.699	.749	.800	.850	.899	.950	1.00
3456	Δ F.E.M	.014	.041	.079	.124	.175	.228	.283	.340	.396	.453	.512	.568	.625	.681	.737	.789	.842	.895	.947	1.00
.999	Δ REGR.	.018	.045	.082	.127	.176	.230	.287	.345	.405	.464	.523	.580	.636	.691	.744	.795	.847	.898	.950	1.00
3840	Δ F.E.M	.014	.038	.073	.115	.163	.214	.268	.323	.380	.438	.494	.554	.610	.669	.725	.781	.837	.892	.948	1.00
.999	Δ REGR.	.016	.041	.074	.114	.160	.210	.263	.319	.375	.435	.494	.551	.608	.666	.722	.777	.834	.889	.945	1.00

TABLE 16

EXPANDED FORM OF THE REGRESSION EQUATION

$$
\begin{aligned}
\delta = {} & \left[(B_1 + B_2S + B_3S^2 + B_4S^3)*(1) + (B_5 + B_6S + B_7S^2 + B_8S^3)*(Z)\right]*X \\
+ & \left[(B_9 + B_{10}S + B_{11}S^2 + B_{12}S^3)*(1) + (B_{13} + B_{14}S + B_{15}S^2 + B_{16}S^3)*(Z)\right]*X^2 \\
+ & \left[(B_{17} + B_{18}S + B_{19}S^2 + B_{20}S^3)*(1) + (B_{21} + B_{22}S + B_{23}S^2 + B_{24}S^3)*(Z)\right]*X^3 \\
+ & \left[(B_{25} + B_{26}S + B_{27}S^2 + B_{28}S^3)*(1) + (B_{29} + B_{30}S + B_{31}S^2 + B_{32}S^3)*(Z)\right]*X^4
\end{aligned}
$$

REGRESSION COEFFICIENTS (TRUNCATED VALUES)

B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8
-.415	-2.36	9.63	-8.29	2.96	-3.91	-4.33	6.81
B_9	B_{10}	B_{11}	B_{12}	B_{13}	B_{14}	B_{15}	B_{16}
-5.41	4.59	43.91	-52.73	29.89	-84.72	55.45	11.55
B_{17}	B_{18}	B_{19}	B_{20}	B_{21}	B_{22}	B_{23}	B_{24}
10.52	3.16	-98.25	104.72	-53.12	134.47	-65.36	-38.75
B_{25}	B_{26}	B_{27}	B_{28}	B_{29}	B_{30}	B_{31}	B_{32}
-3.69	-5.45	44.78	-43.71	20.24	-45.69	14.00	20.48

TABLE 17

DEFLECTION PROFILE VALUES
(BASED ON TRUNCATED POLYNOMIAL COEFFICIENTS)
FRAME 1R (8-STORY STRUCTURE)

		STORY NUMBERS							
		1	2	3	4	5	6	7	8
		NORMALIZED DEFLECTION VALUES							
SHEAR AREA 720 in^2 R^2=.9995	$\triangle$F.E.M.	.138	.279	.425	.565	.692	.804	.906	1.00
	$\triangle$REGRESS	.137	.272	.418	.560	.687	.797	.896	.992
SHEAR AREA 960 in^2 R^2=.9997	$\triangle$F.E.M.	.107	.228	.363	.501	.634	.761	.882	1.00
	$\triangle$REGRESS	.112	.229	.362	.499	.631	.754	.873	.992
SHEAR AREA 1200 in^2 R^2=.9996	$\triangle$F.E.M.	.098	.207	.336	.473	.605	.742	.871	1.00
	$\triangle$REGRESS	.097	.205	.332	.467	.602	.733	.862	.991
SHEAR AREA 1440 in^2 R^2=.9998	$\triangle$F.E.M.	.093	.207	.336	.473	.605	.742	.871	1.00
	$\triangle$REGRESS	.091	.195	.320	.455	.592	.726	.859	.991
SHEAR AREA 1680 in^2 R^2=.9996	$\triangle$F.E.M.	.092	.192	.315	.446	.585	.723	.862	1.00
	$\triangle$REGRESS	.089	.193	.319	.455	.593	.728	.860	.990

TABLE 18

DEFLECTION PROFILE VALUES (BASED ON TRUNCATED POLYNOMIAL COEFFICIENTS) FRAME 2R (10-STORY STRUCTURE)											
		STORY NUMBER									
		1	2	3	4	5	6	7	8	9	10
		NORMALIZED DEFLECTION VALUES									
SHEAR AREA 1152 in^2	$\triangle$ F.E.M.	.083	.201	.330	.458	.578	.688	.785	.869	.940	1.00
R^2=.9995	$\triangle$ REGRESS.	.087	.197	.323	.453	.577	.688	.782	.860	.928	.991
SHEAR AREA 1440 in^2	$\triangle$ F.E.M.	.070	.175	.295	.417	.537	.650	.753	.845	.927	1.00
R^2=.9975	$\triangle$ REGRESS.	.073	.168	.282	.401	.520	.632	.734	.825	.909	.990
SHEAR AREA 1728 in^2	$\triangle$ F.E.M.	.062	.154	.266	.383	.501	.617	.723	.822	.914	1.00
R^2=.9985	$\triangle$ REGRESS.	.064	.151	.258	.372	.489	.602	.708	.805	.898	.990
SHEAR AREA 2016 in^2	$\triangle$ F.E.M.	.055	.139	.244	.357	.473	.588	.701	.805	.906	1.00
R^2=.9993	$\triangle$ REGRESS.	.058	.140	.241	.353	.469	.582	.691	.793	.892	.989
SHEAR AREA 2304 in^2	$\triangle$ F.E.M.	.051	.130	.229	.338	.454	.560	.681	.789	.896	1.00
R^2=.9992	$\triangle$ REGRESS.	.051	.126	.223	.330	.444	.558	.671	.778	.883	.989

TABLE 19

DEFLECTION PROFILE VALUES
(BASED ON TRUNCATED POLYNOMIAL COEFFICIENTS)
FRAME 3R (20-STORY STRUCTURE)

SHEAR AREA R^2		STORY NUMBER																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
		NORMALIZED DEFLECTION VALUES																			
2304	Δ F.E.M	.022	.065	.121	.187	.254	.320	.381	.441	.496	.553	.604	.655	.704	.753	.797	.841	.883	.922	.961	1.00
.9963	Δ REGR.	.095	.076	.125	.183	.244	.308	.371	.434	.496	.553	.608	.659	.705	.749	.789	.827	.864	.901	.942	.985
2688	Δ F.E.M	.019	.053	.101	.158	.218	.229	.337	.395	.453	.511	.566	.619	.671	.724	.773	.820	.867	.912	.956	1.00
.9987	Δ REGR.	.026	.059	.100	.150	.203	.260	.318	.376	.435	.491	.547	.599	.650	.699	.745	.791	.837	.882	.931	.982
3072	Δ F.E.M	.016	.046	.088	.138	.193	.249	.306	.364	.421	.480	.536	.592	.645	.701	.754	.804	.854	.903	.953	1.00
.9971	Δ REGR.	.020	.049	.087	.132	.182	.237	.293	.350	.409	.466	.523	.577	.630	.682	.731	.780	.829	.877	.927	.979
3456	Δ F.E.M	.014	.041	.079	.124	.175	.228	.283	.340	.396	.453	.512	.568	.625	.681	.737	.789	.842	.895	.947	1.00
.9956	Δ REGR.	.017	.044	.079	.122	.170	.223	.278	.335	.393	.451	.508	.564	.618	.672	.724	.774	.825	.874	.925	.977
3840	Δ F.E.M	.014	.308	.073	.115	.163	.214	.268	.323	.380	.438	.494	.554	.610	.669	.725	.781	.837	.892	.948	1.00
.9987	Δ REGR.	.015	.038	.070	.109	.153	.203	.254	.308	.365	.421	.478	.534	.590	.646	.700	.754	.809	.863	.919	.975

F I G U R E S

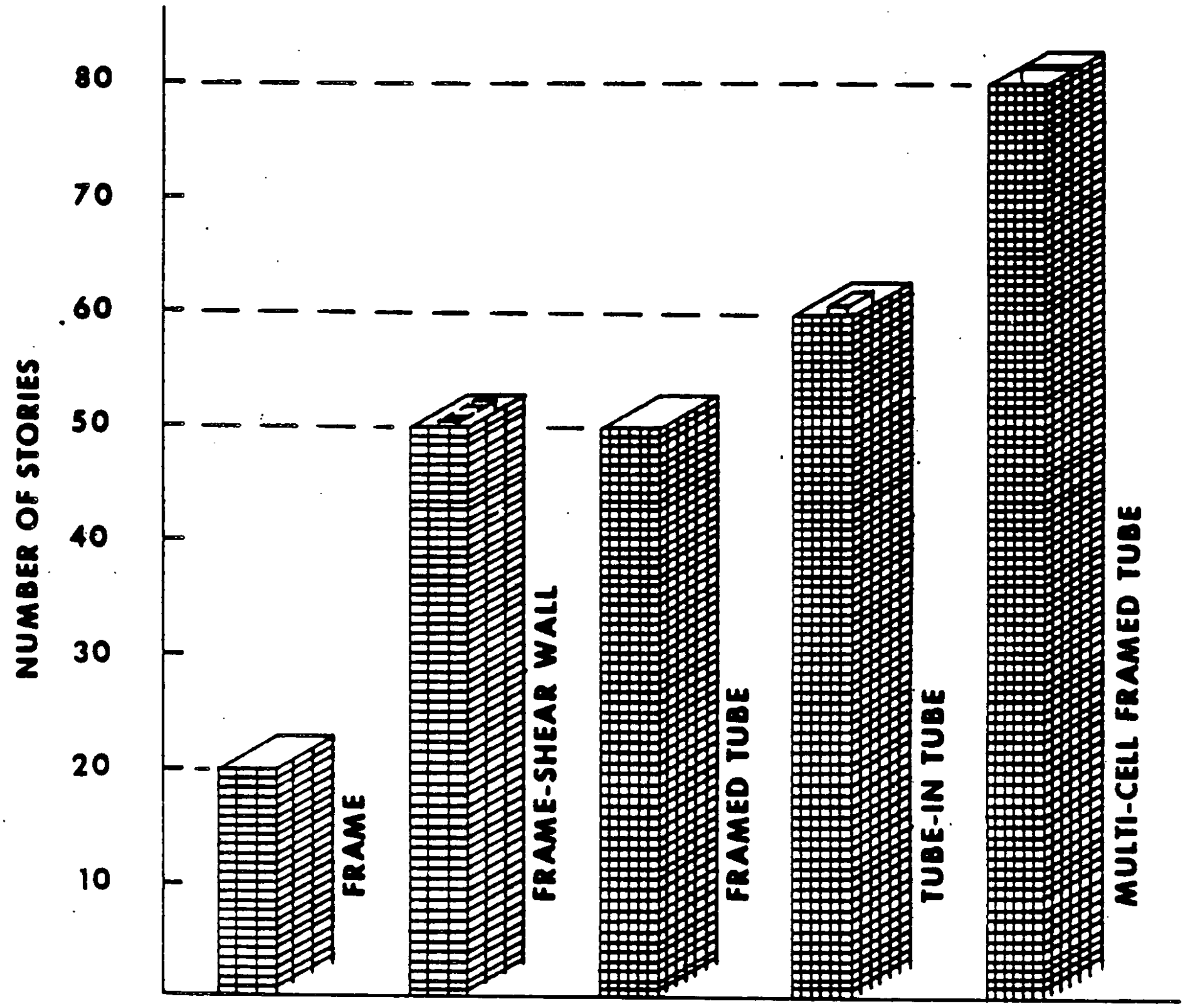


FIG. 1 LATERAL LOAD RESISTING SYSTEMS FOR BUILDINGS (REF. 7)

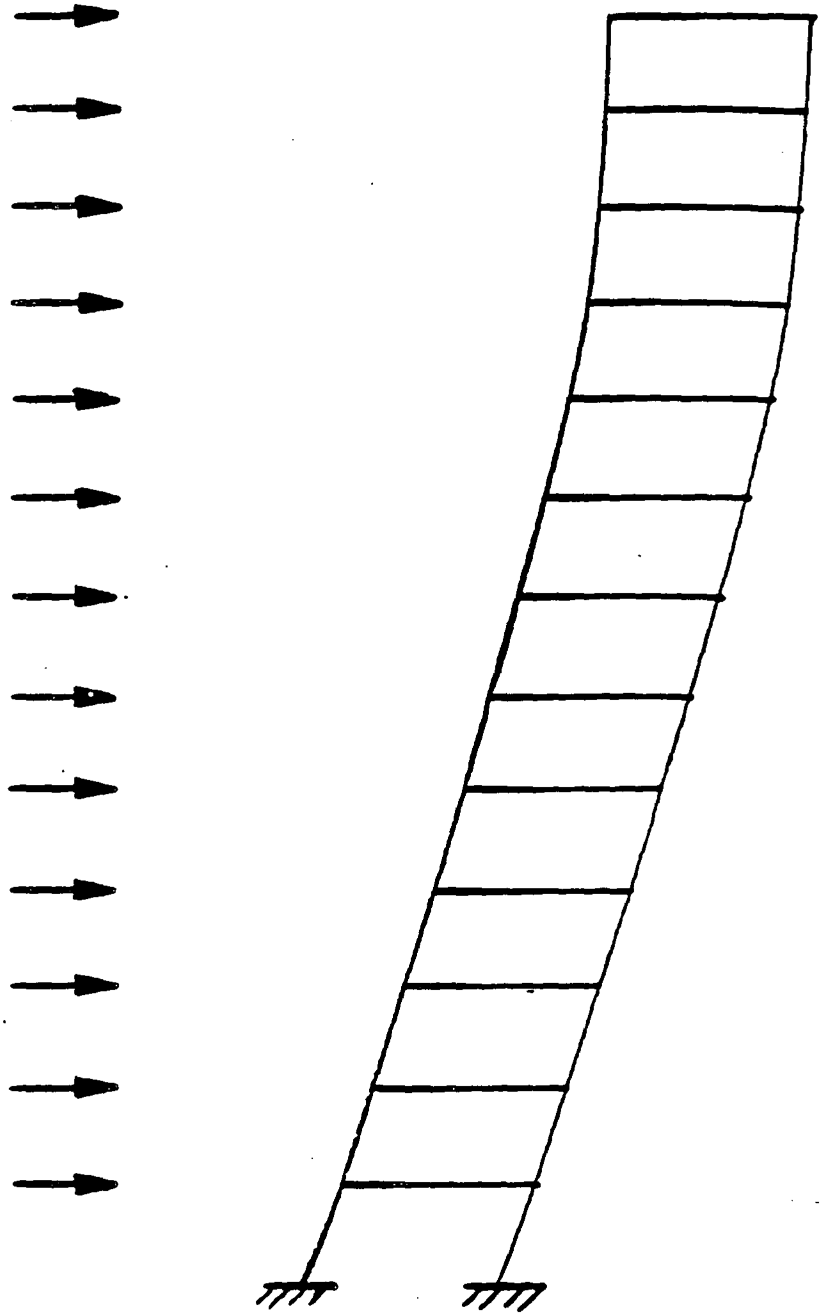


FIG. 2 RIGID FRAME DEFORMATION

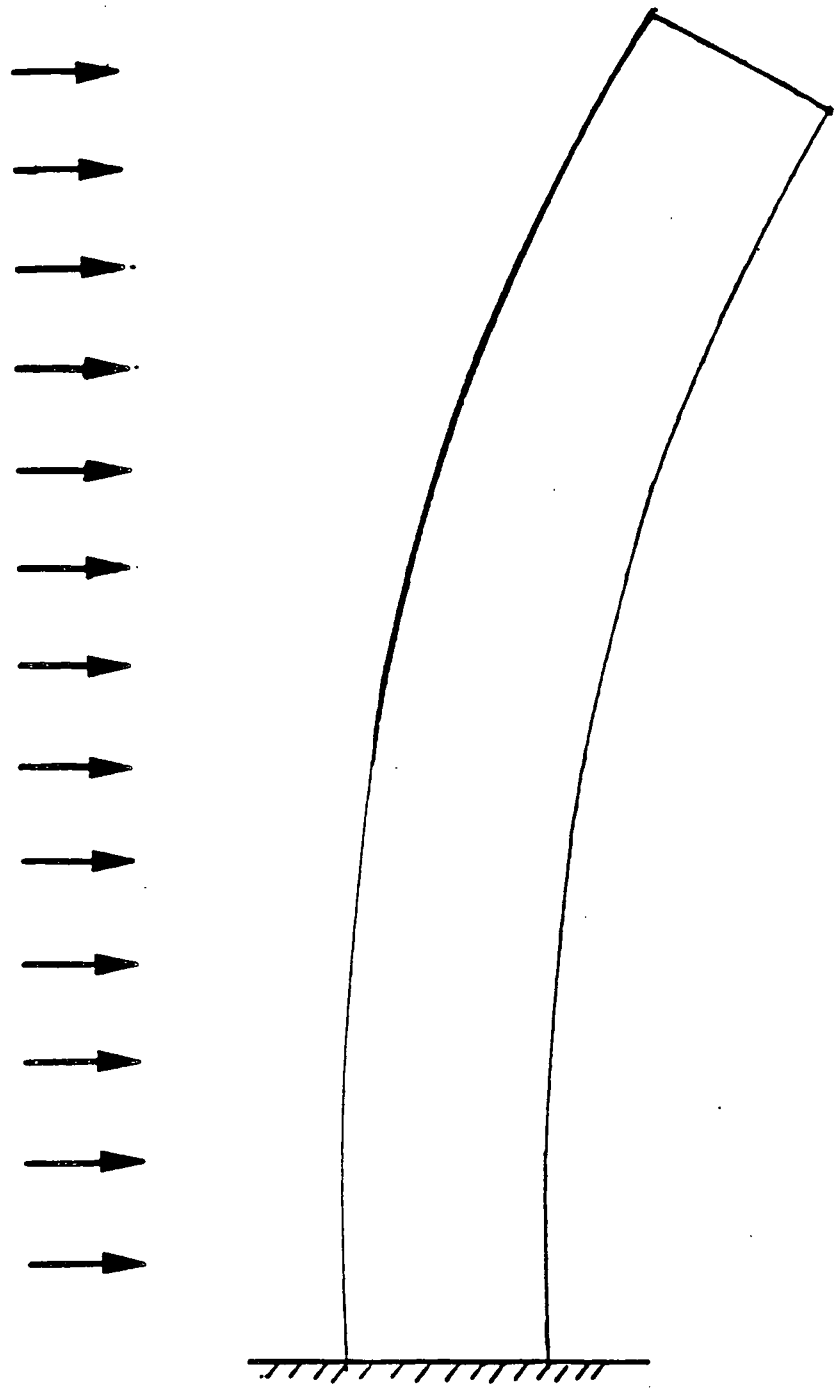


FIG. 3 SHEAR WALL DEFORMATION

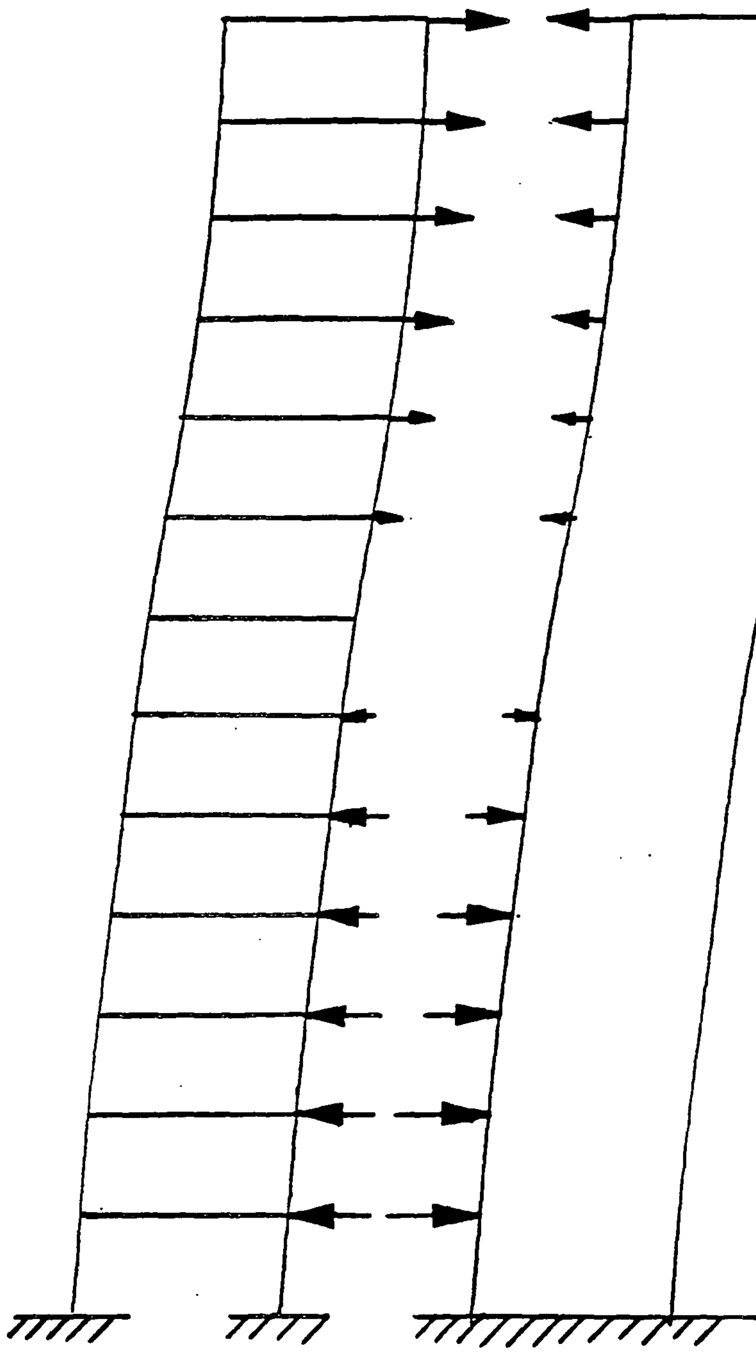


FIG. 4 FRAME-SHEAR WALL INTERACTION

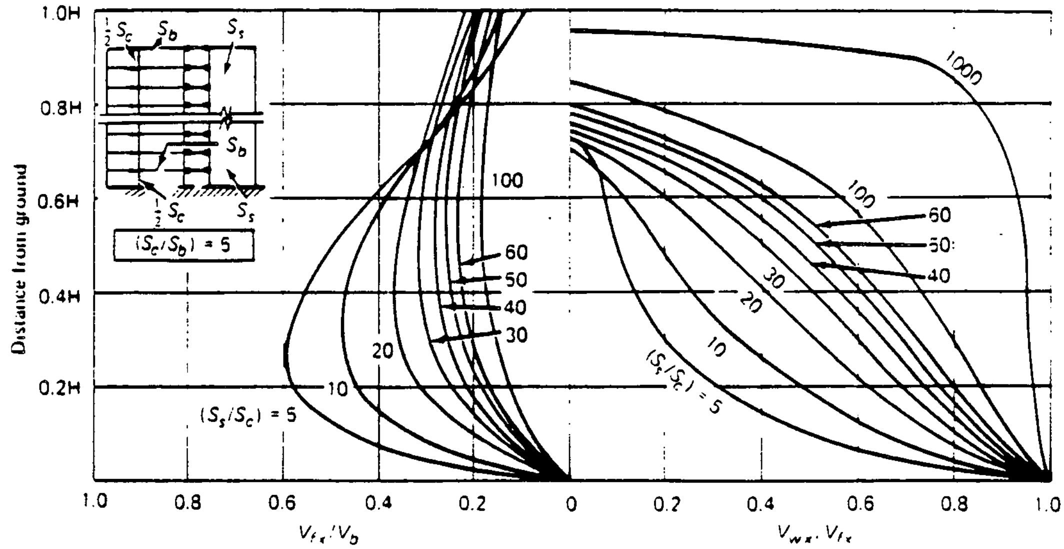


FIG. 5 SHEAR WALL-FRAME LATERAL LOAD DISTRIBUTION CURVES (REF. 8)

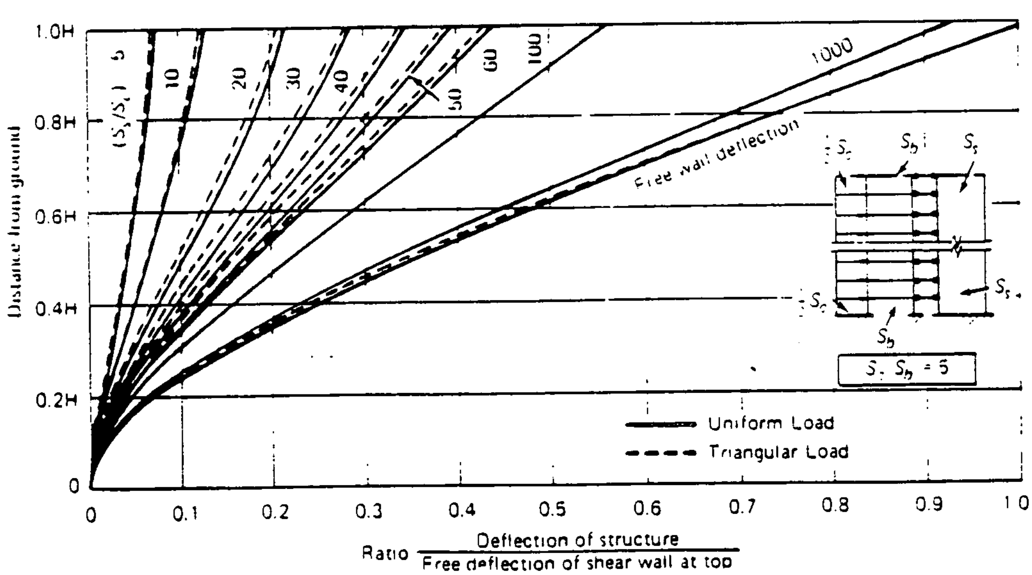


FIG. 6 DEFLECTED SHAPE OF SHEAR WALL-FRAME INTERACTIVE SYSTEM (REF. 8)

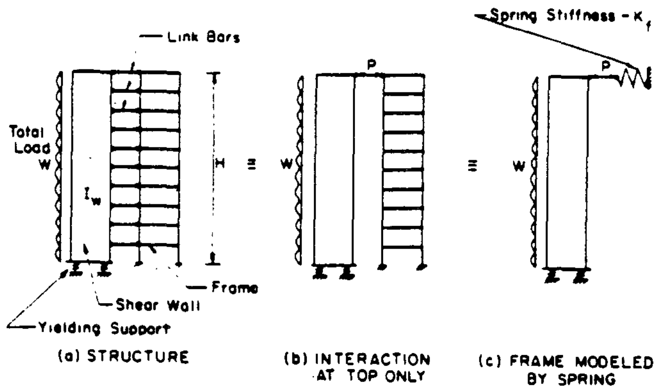


FIG. 7 (REF. 9)

Load condition	Equation C
Point load at top	$\dfrac{P}{W} = \dfrac{1 + \dfrac{3}{4\gamma_w}}{1 + \dfrac{3}{4\gamma_w} + \dfrac{K_w}{K_f}}$
Uniformly distributed	$\dfrac{P}{W} = \dfrac{\dfrac{3}{8}\left(1 + \dfrac{1}{\gamma_w}\right)}{1 + \dfrac{3}{4\gamma_w} + \dfrac{K_w}{K_f}}$
Triangular (earthquake)	$\dfrac{P}{W} = \dfrac{\dfrac{11}{20} + \dfrac{1}{2\gamma_w}}{1 + \dfrac{3}{4\gamma_w} + \dfrac{K_w}{K_f}}$

NOTATION

W = total applied load
P = interaction force at top
I_w = moment of inertia of wall
H = total height
K_f = point load at top of frame to cause unit deflection in its line of action
$K_w = \dfrac{3EI_w}{H^3}$ (with constant I_w)
K_B = rotational stiffness of shear wall support
$\gamma_w = \dfrac{K_B H}{4E_w I_w}$
top deflection $\Delta = \dfrac{P}{K_f}$

FIG. 8 (REF. 9)

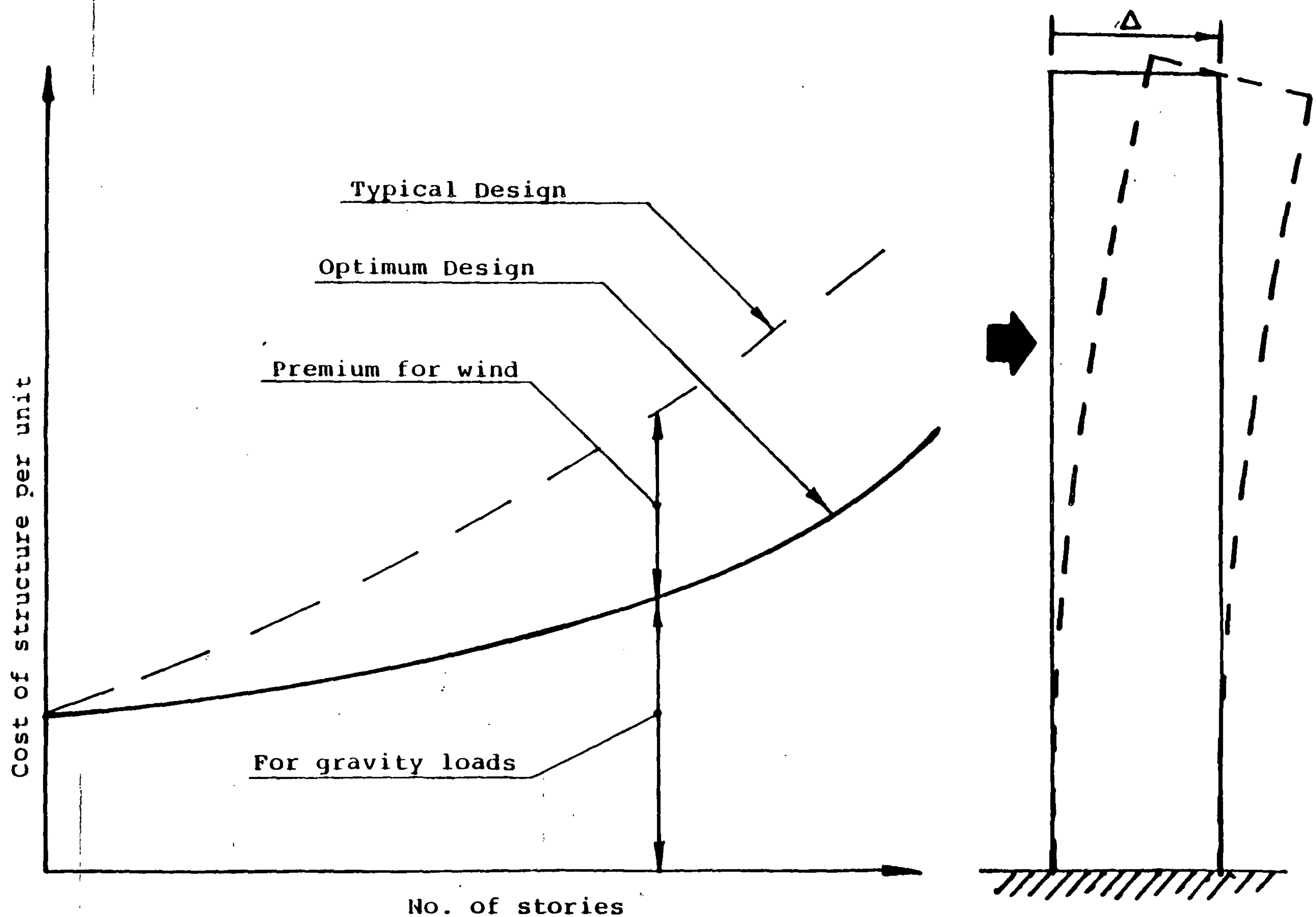


FIG. 9 EFFECT OF LATERAL WIND LOADS ON STRUCTURAL COST

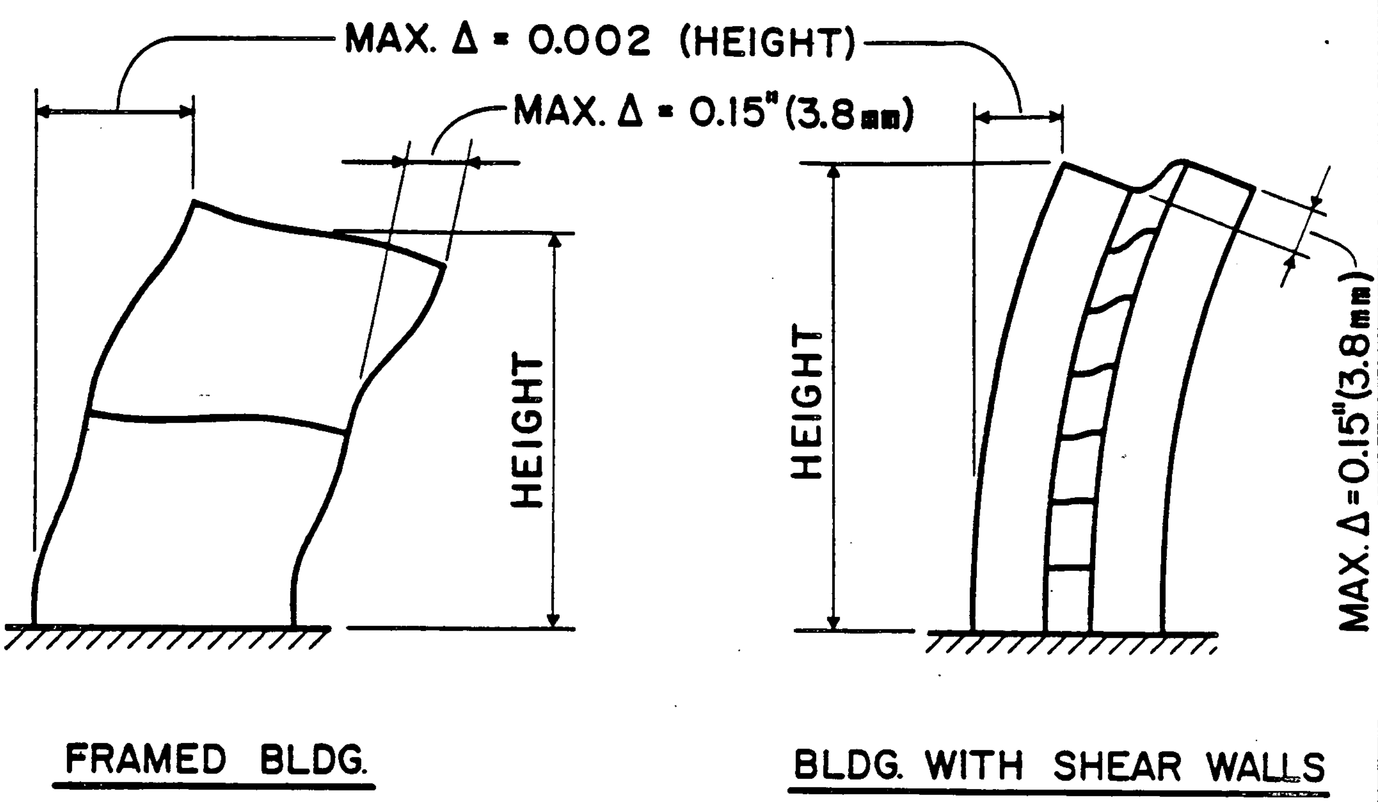
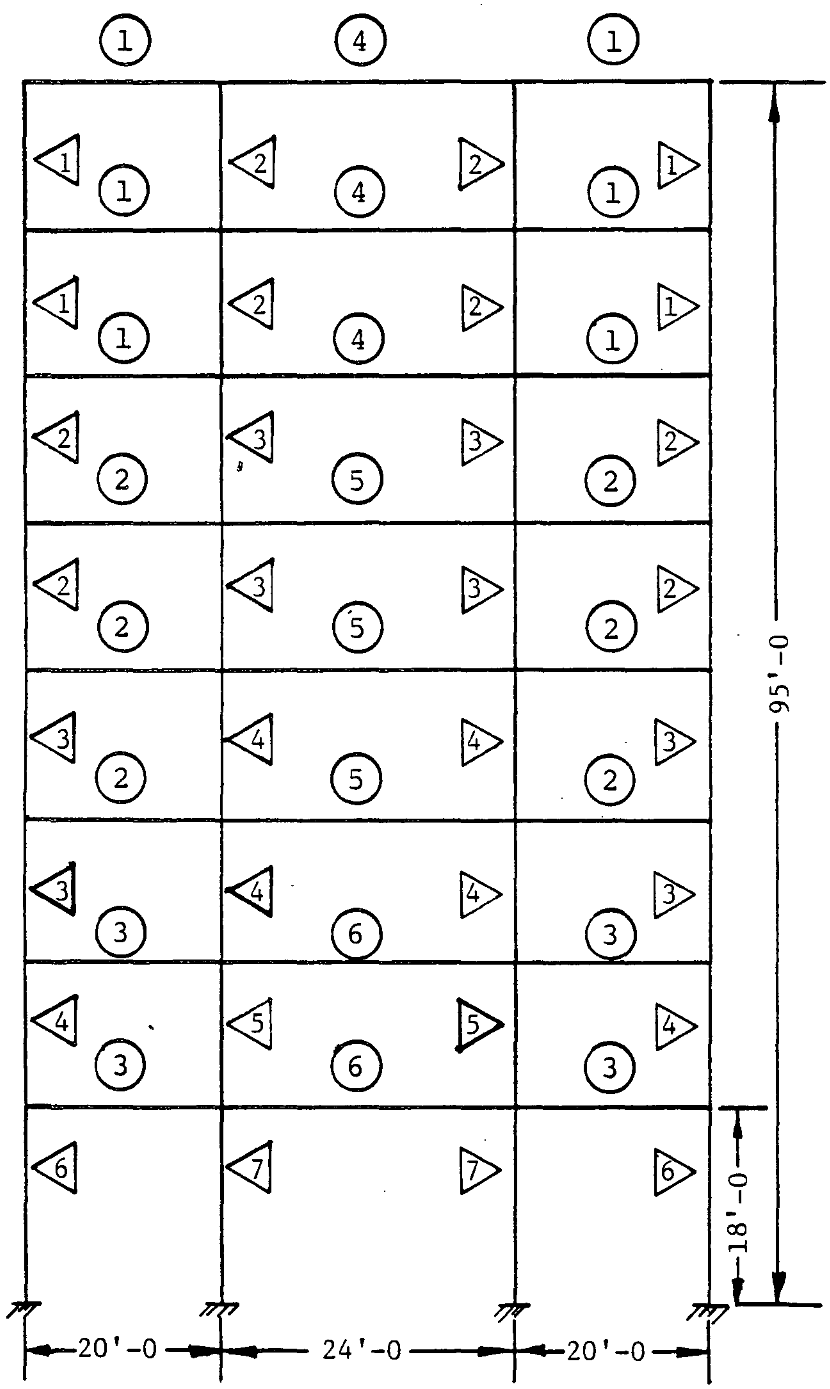


FIG. 10 DRIFT REQUIREMENTS

FIG. 11

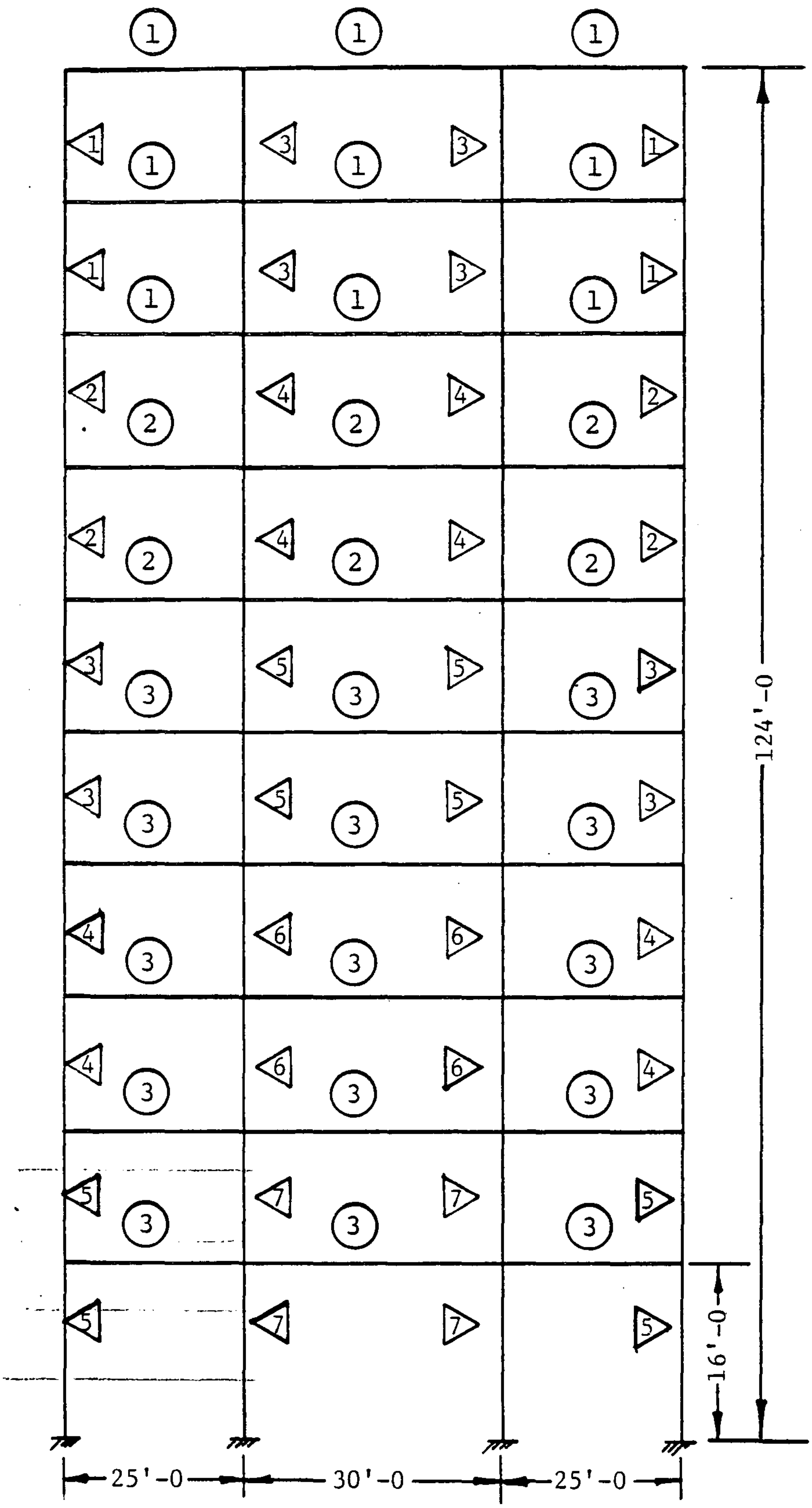
FRAME 1R



MEMBER DIMENSIONS (INCHES)	
BEAMS	
MK	SIZE
1	13x13
2	14x14
3	16x16
4	14x15
5	15x17
6	17x18
COLUMNS	
MK	SIZE
1	13x13
2	14x14
3	15x15
4	16x16
5	17x17
6	18x18
7	19x19

FIG. 12

FRAME 2R



MEMBER DIMENSIONS (INCHES)

BEAMS

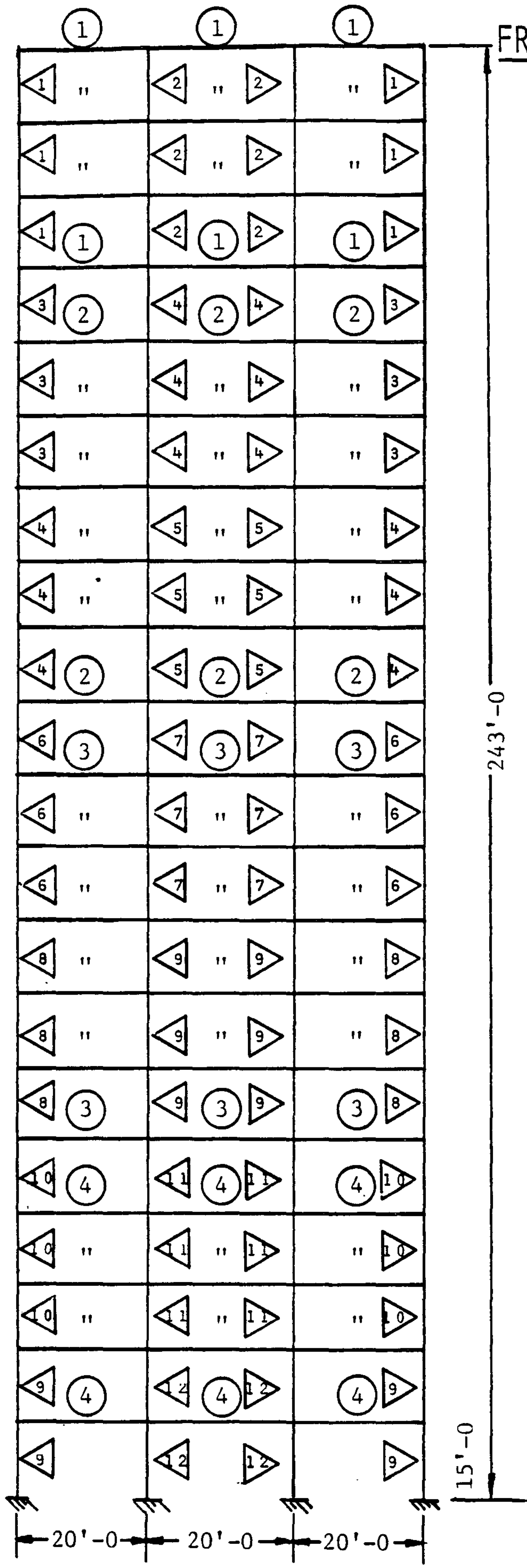
MK	SIZE
1	15x30
2	16x32
3	17x34

COLUMNS

MK	SIZE
1	22x22
2	24x24
3	26x26
4	28x28
5	30x30
6	32x32
7	34x34

FIG. 13

FRAME 3R



MEMBER DIMENSIONS (INCHES)	
BEAMS	
MK	SIZE
1	21x21
2	23x23
3	25x25
4	26x26
COLUMNS	
MK	SIZE
1	14x14
2	18x18
3	16x16
4	19x19
5	22x22
6	21x21
7	24x24
8	23x23
9	26x26
10	25x25
11	30x30
12	31x31

FIG. 14

FRAME-SHEAR WALL CONFIGURATION

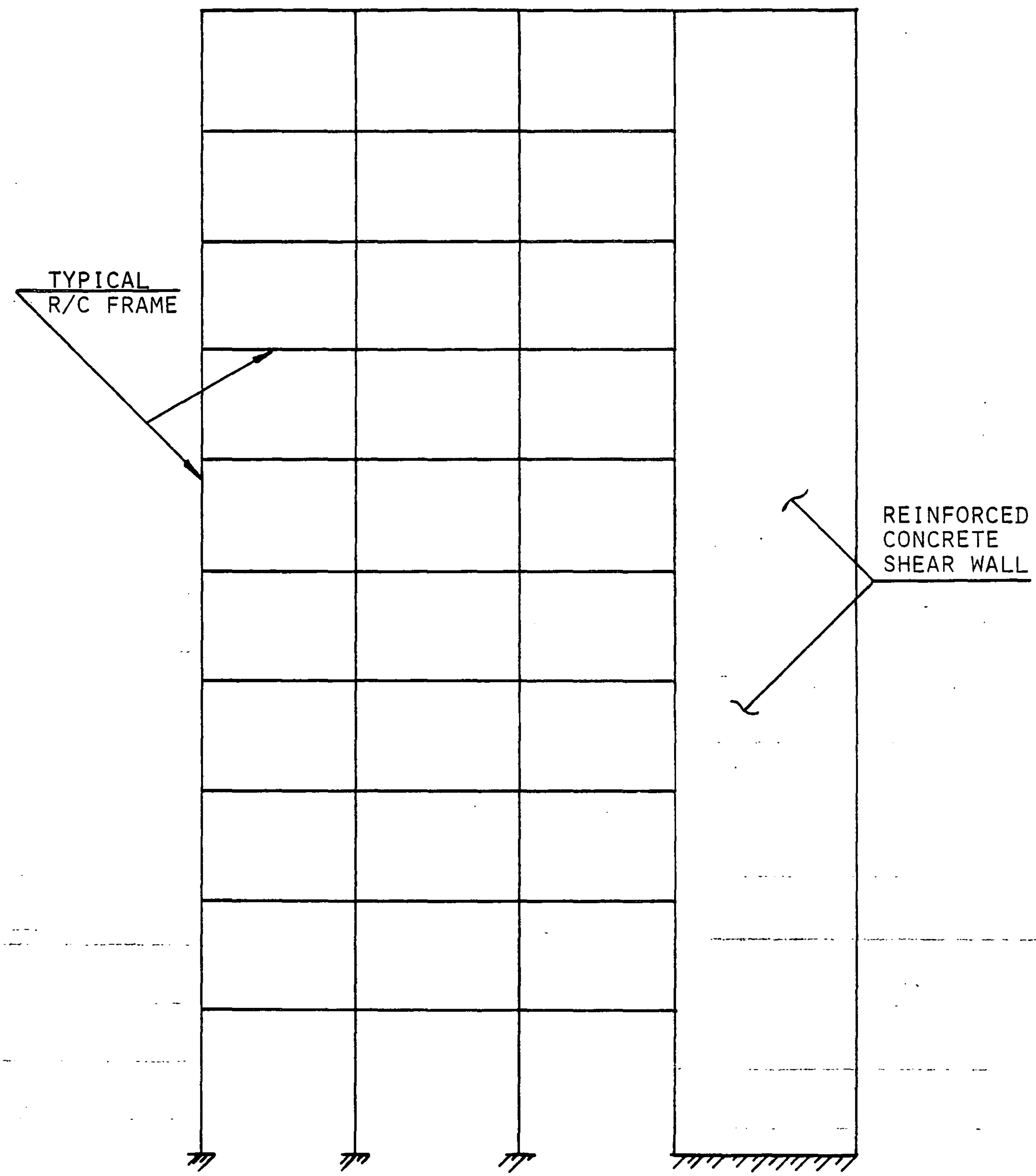


FIG. 15

TYPICAL FINITE ELEMENT DISCRETIZATION

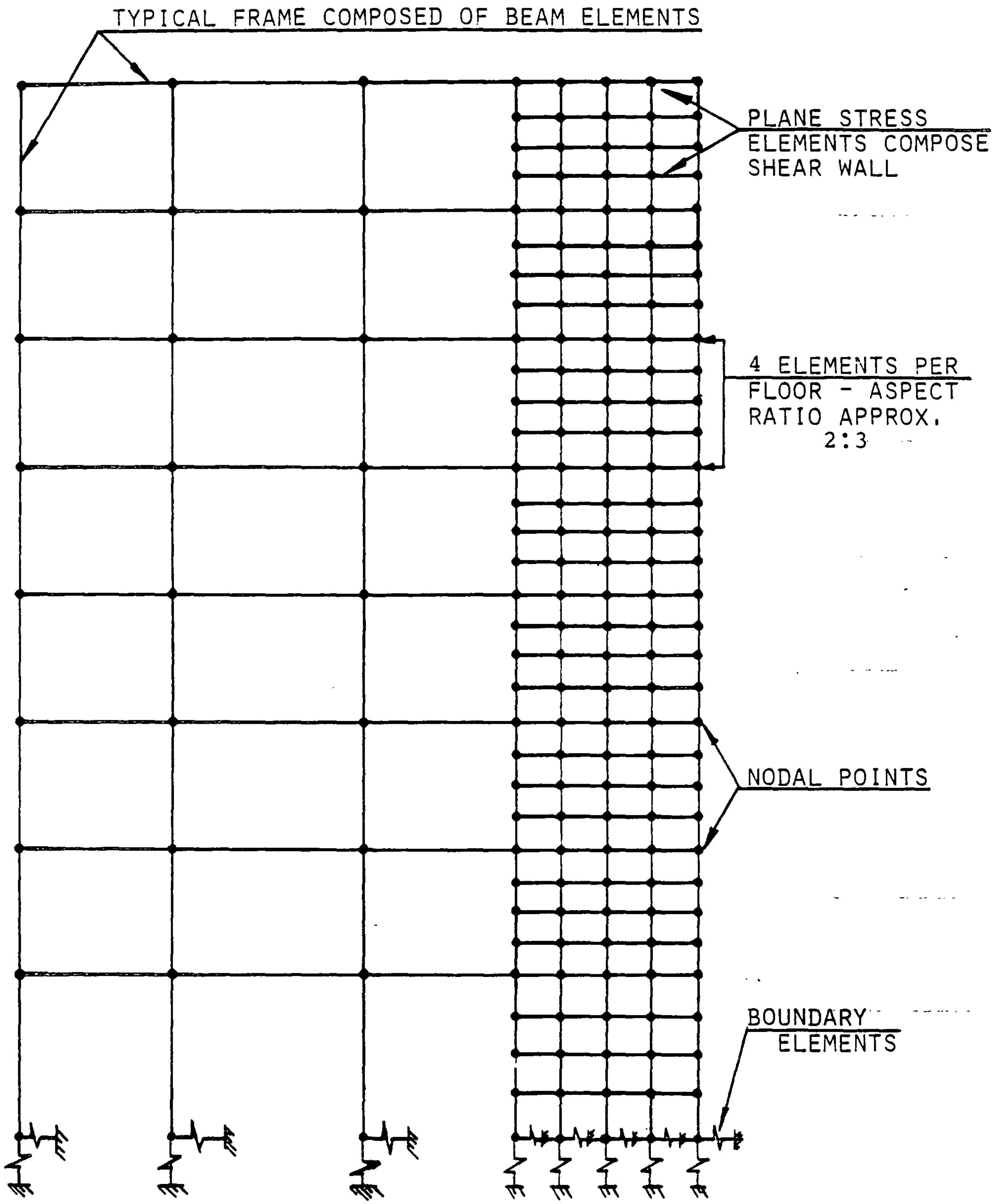
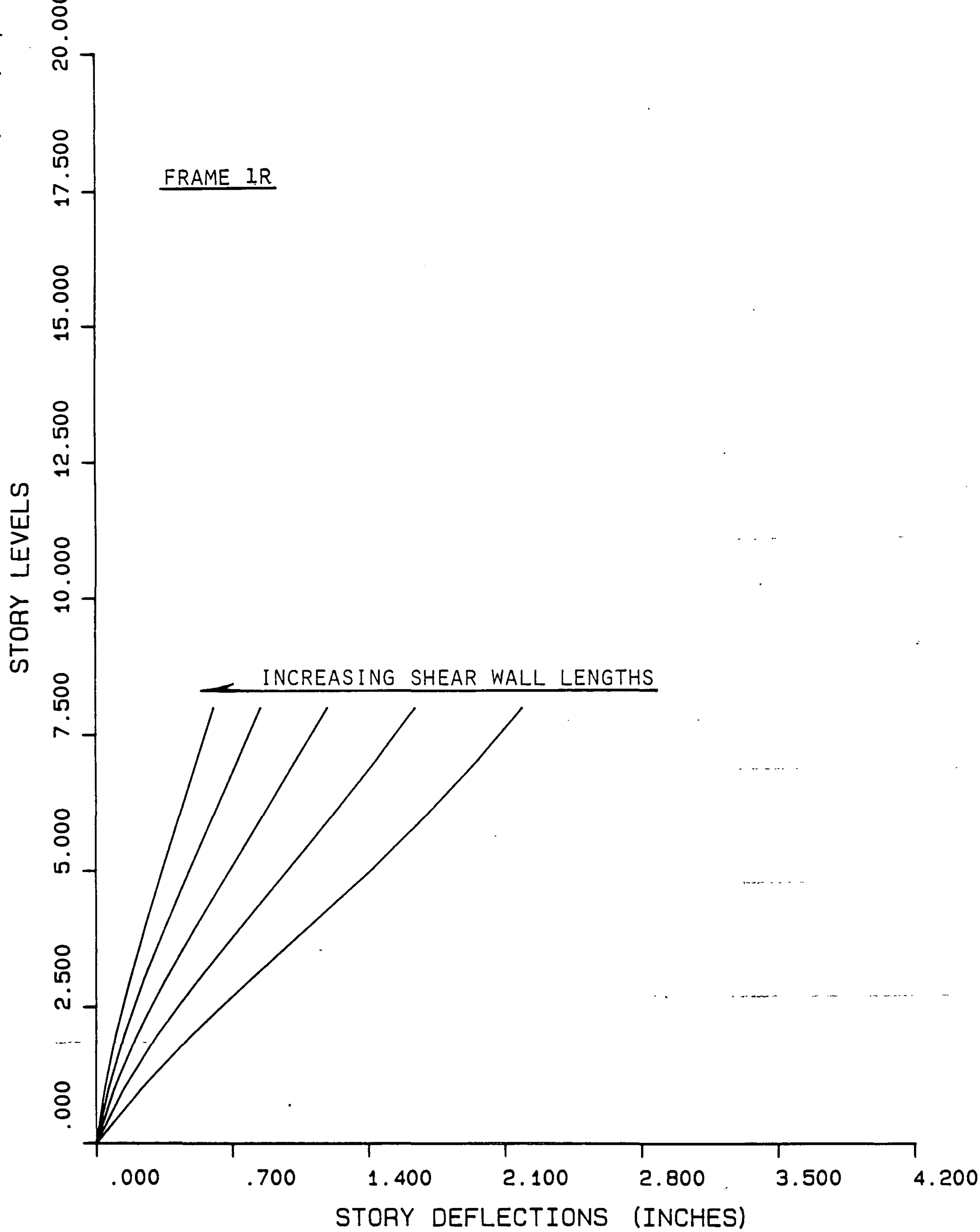
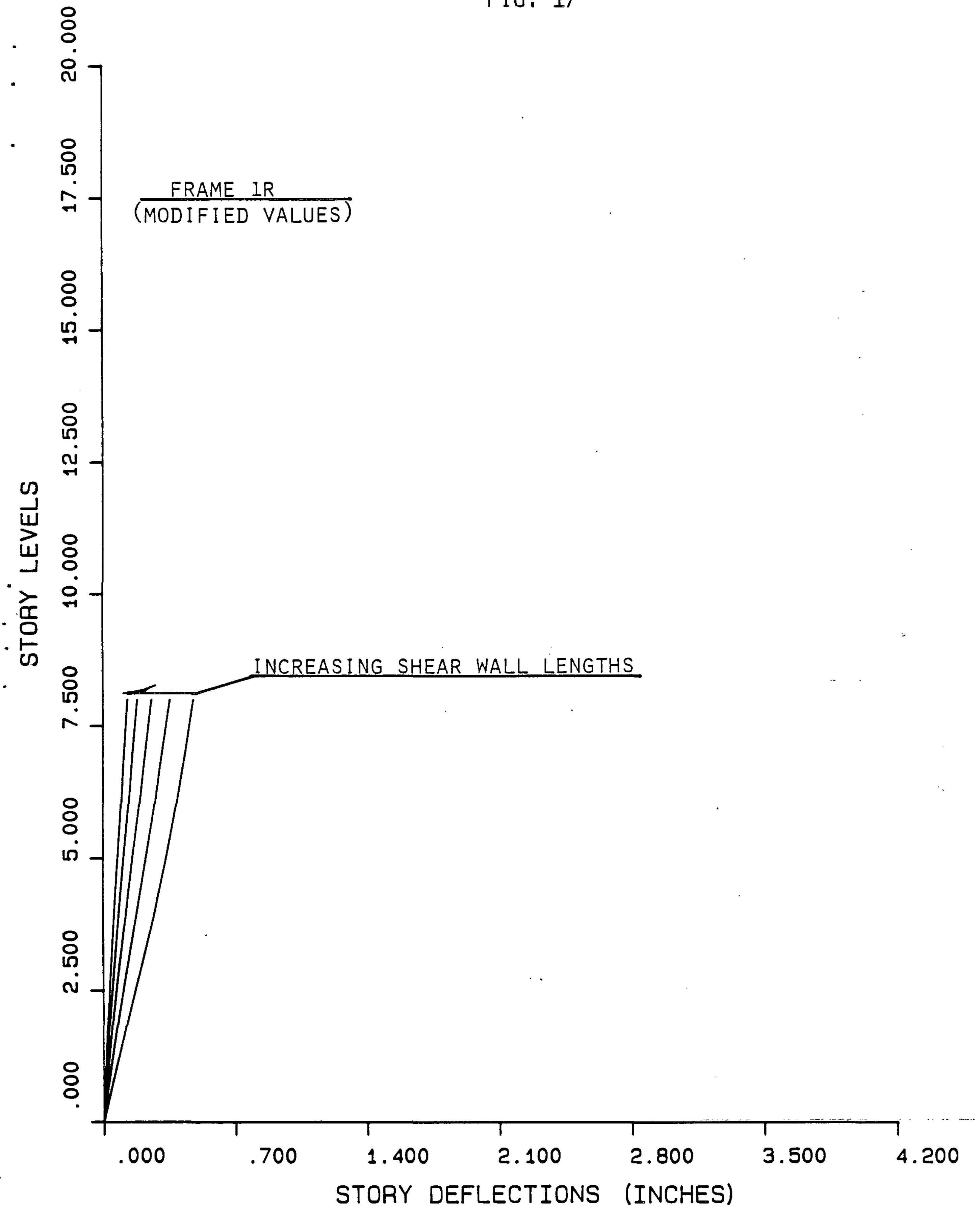


FIG. 16



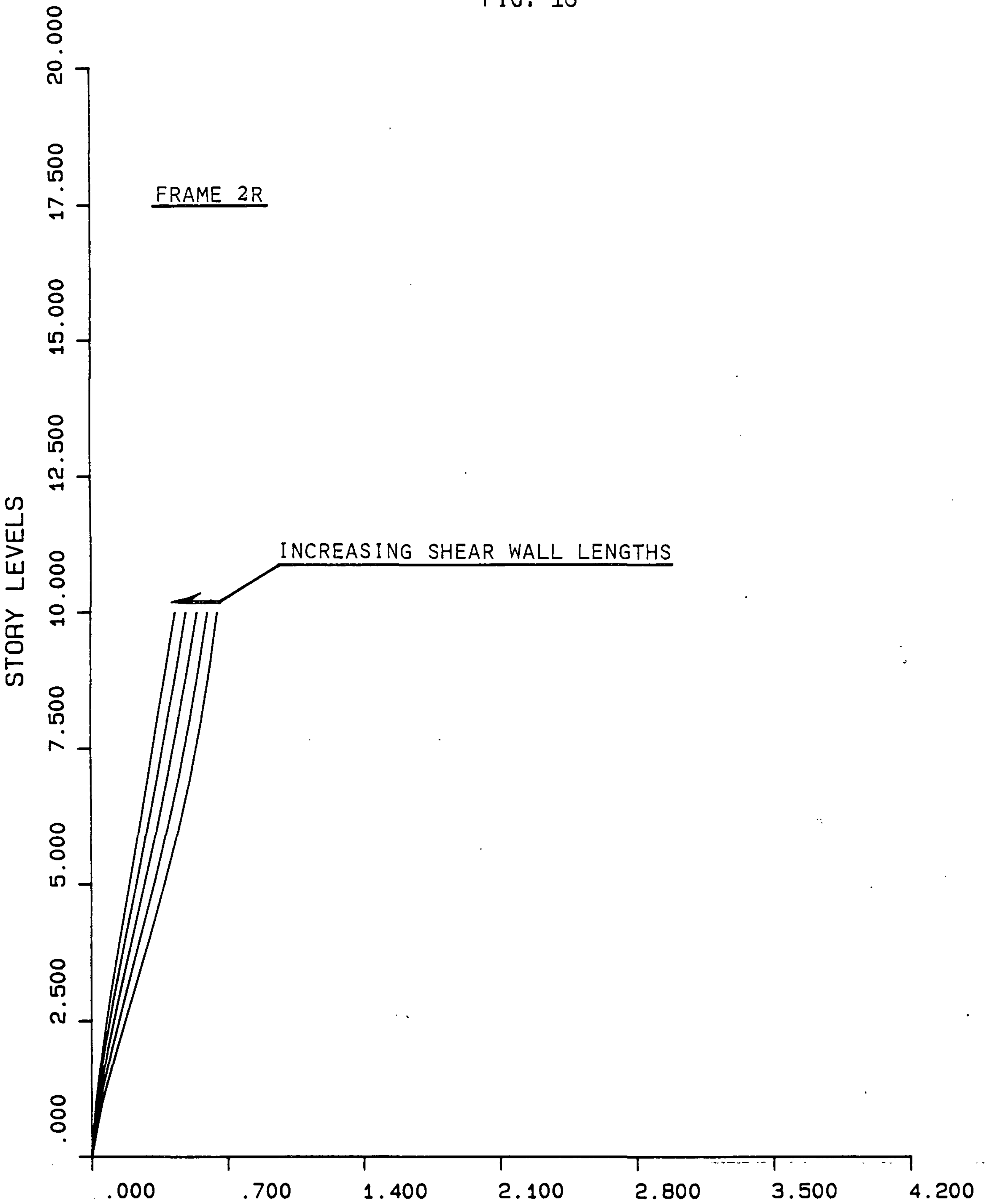
DEFLECTION PROFILES RESULTS OF F.E.M ANALYSIS

FIG. 17



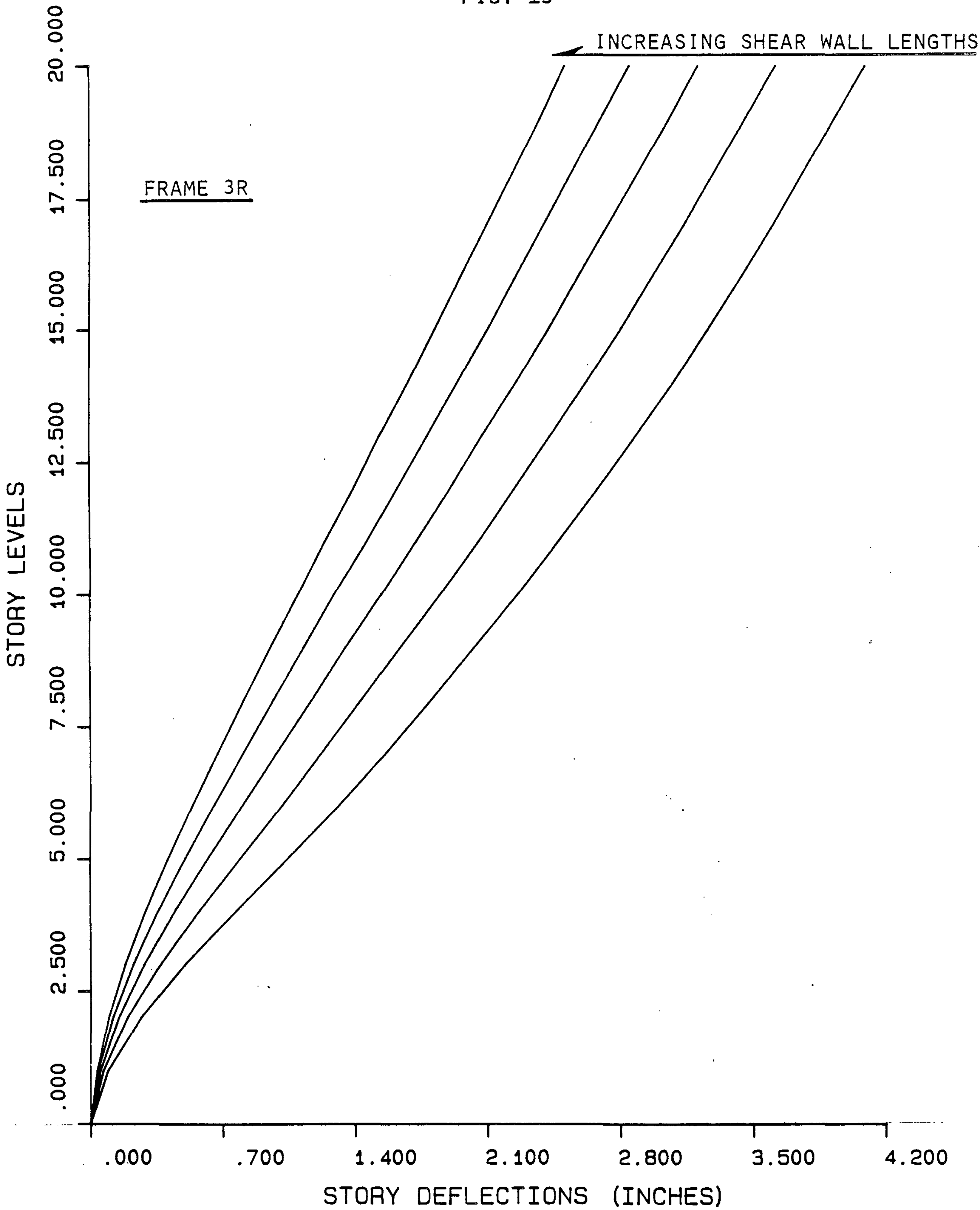
DEFLECTION PROFILES RESULTS OF F.E.M ANALYSIS

FIG. 18



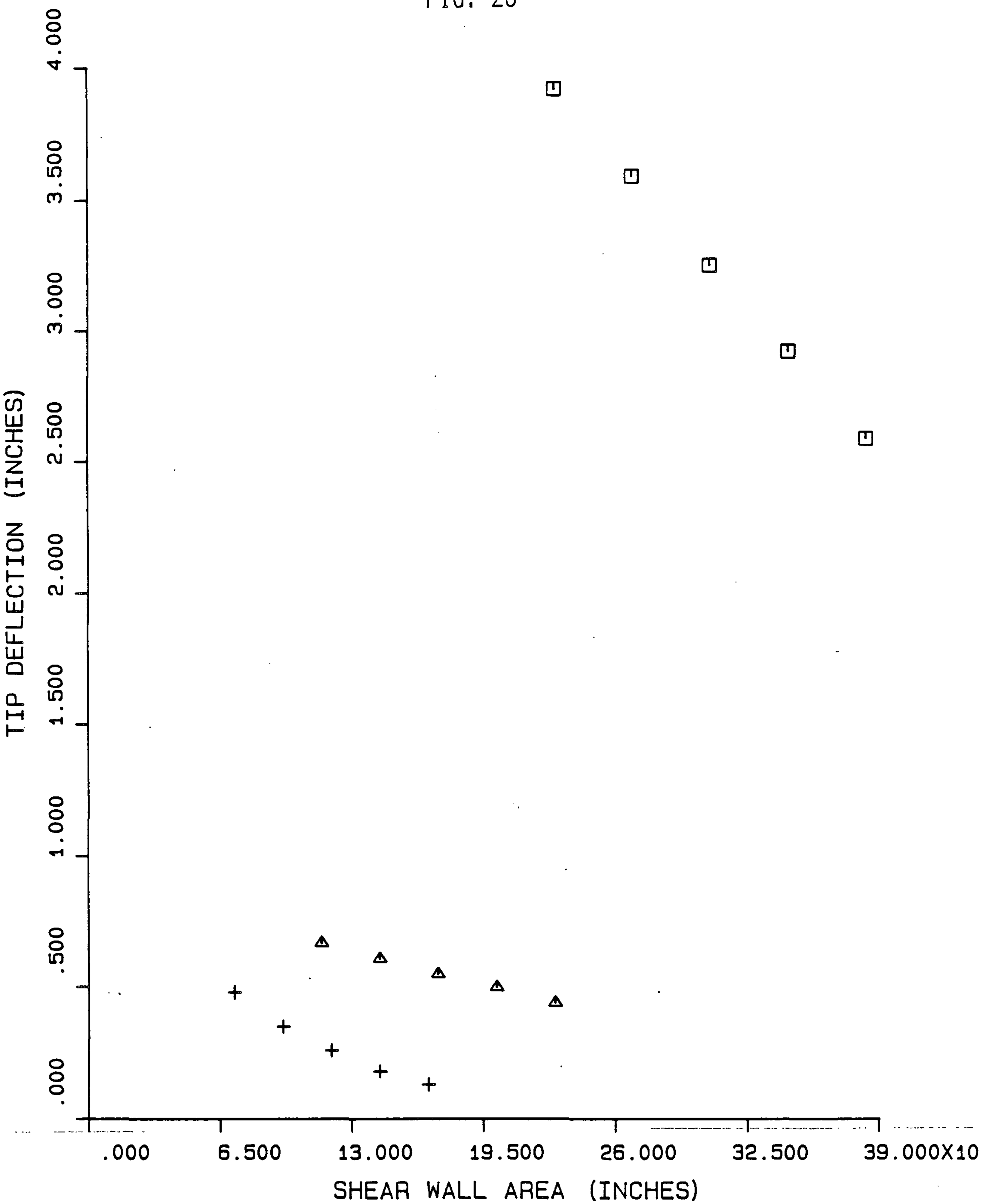
DEFLECTION PROFILES RESULTS OF F.E.M ANALYSIS

FIG. 19



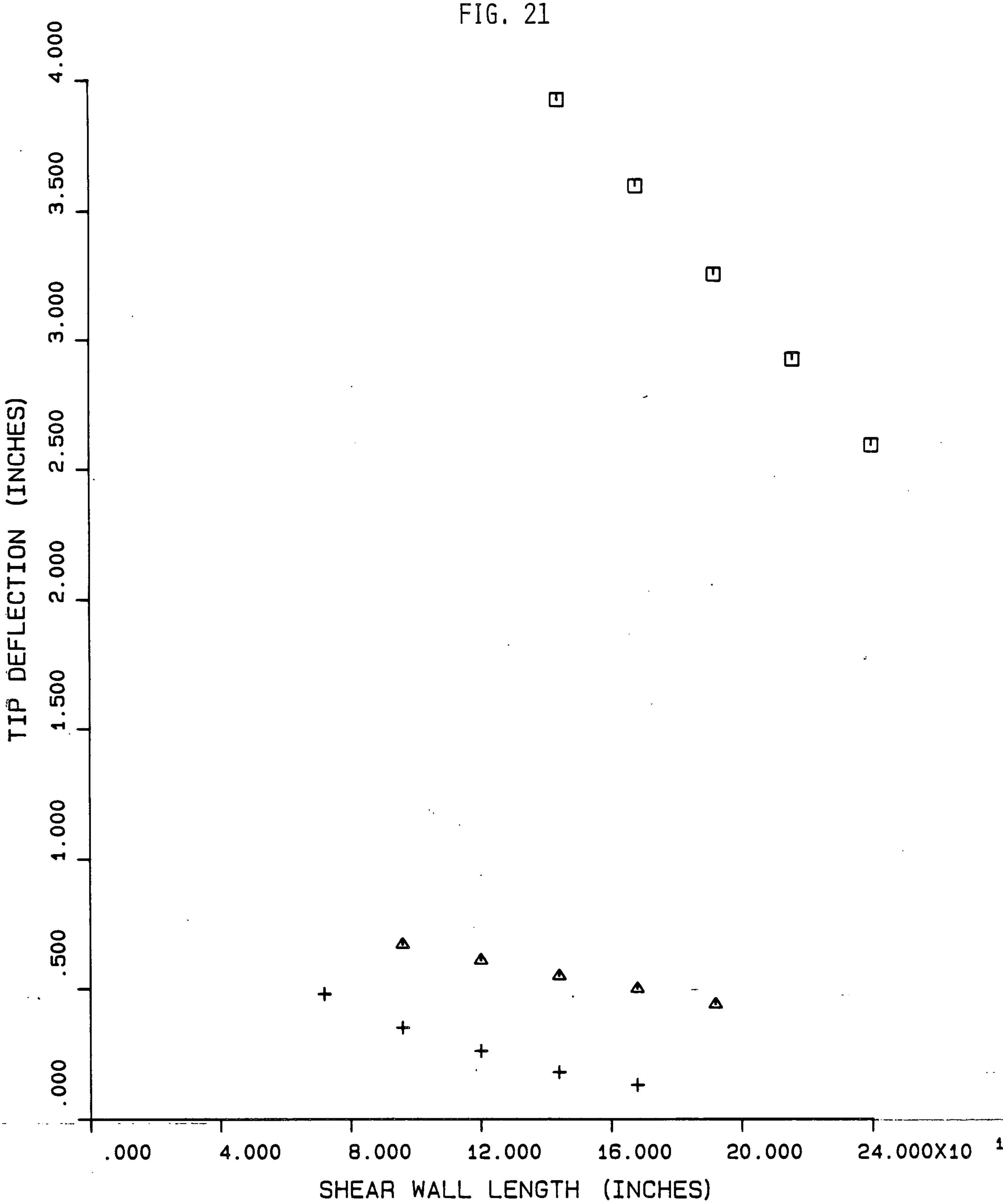
DEFLECTION PROFILES RESULTS OF F.E.M ANALYSIS

FIG. 20



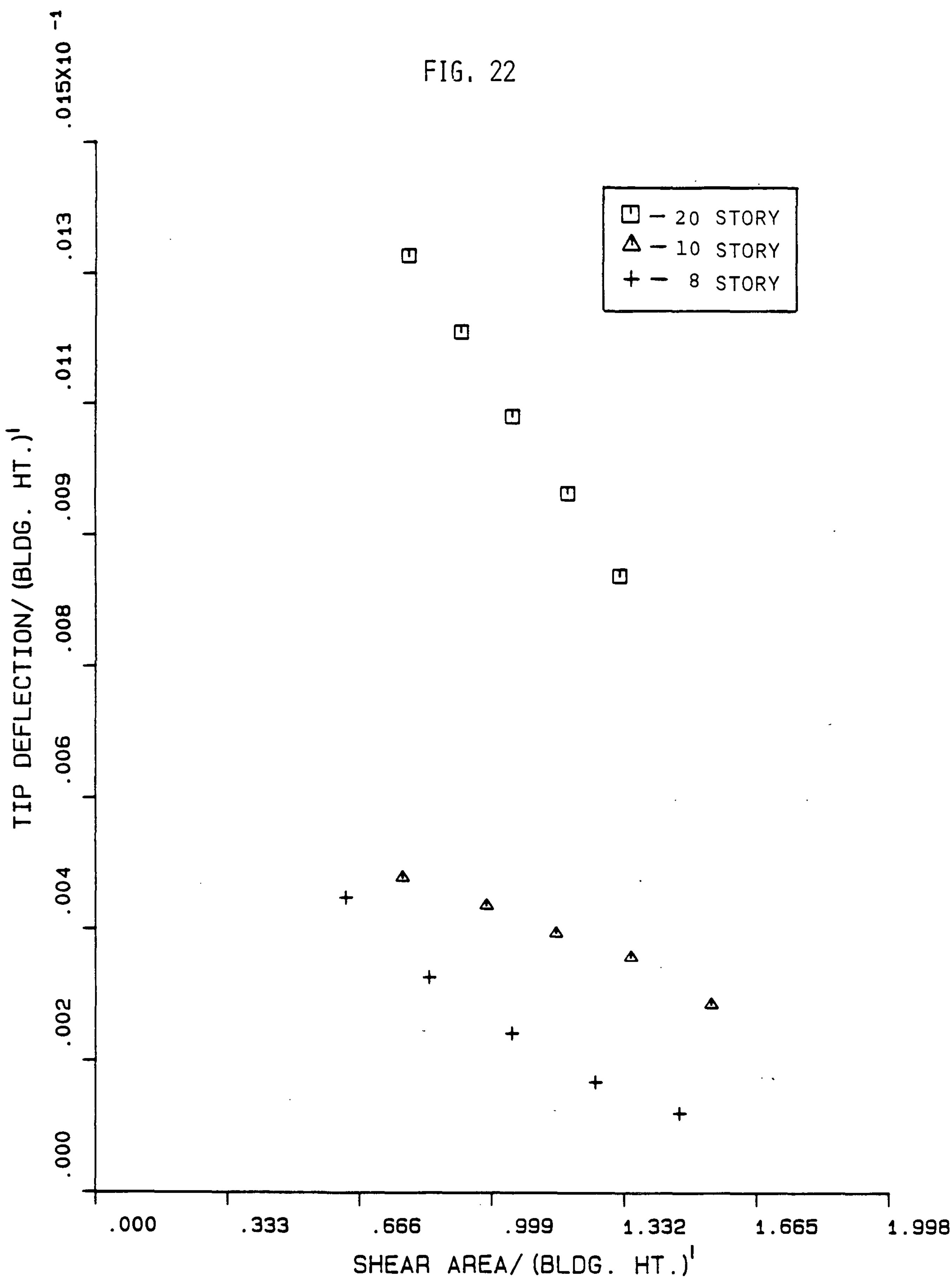
SCATTER DIAGRAM

FIG. 21



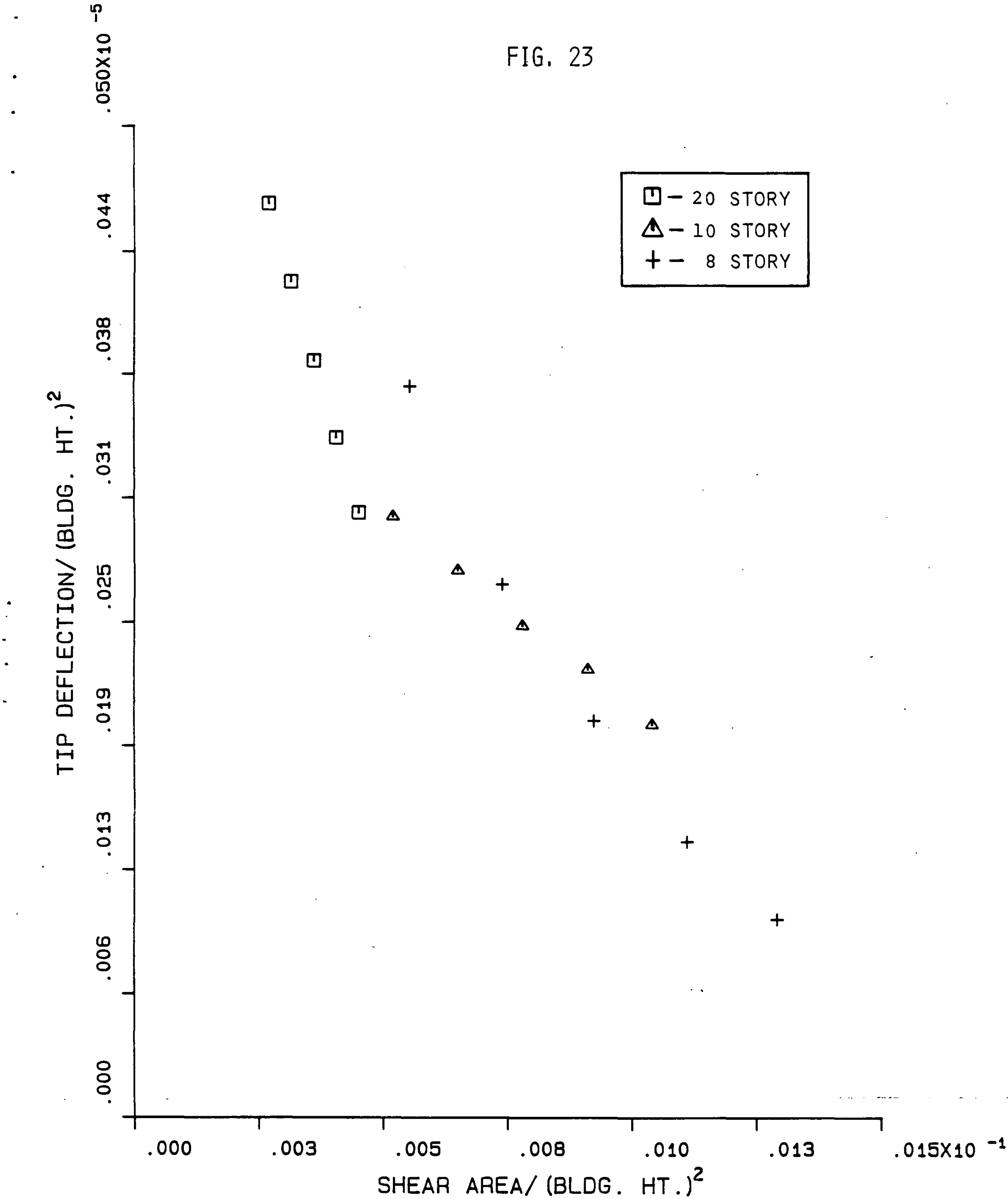
SCATTER DIAGRAM

FIG. 22



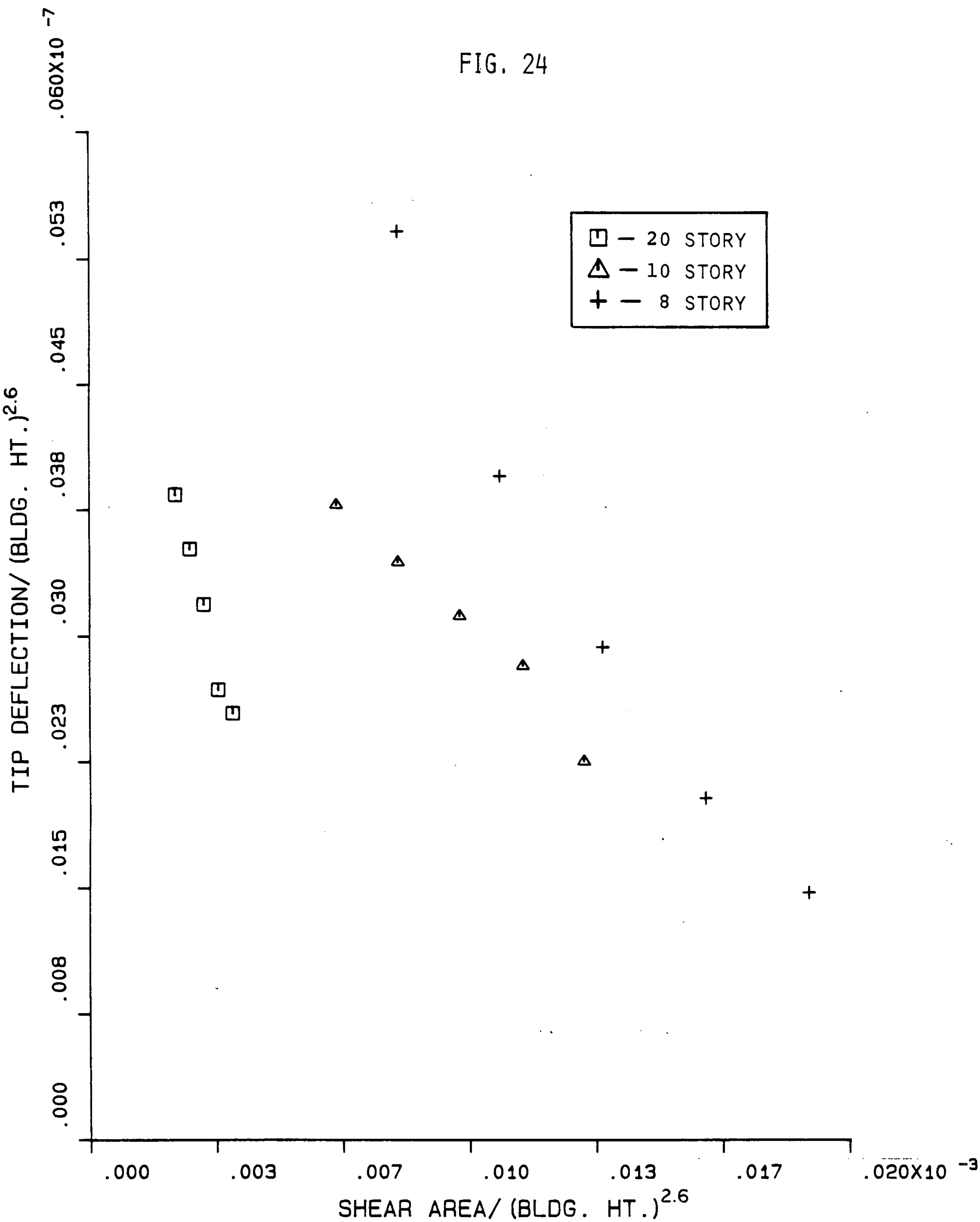
SCATTER DIAGRAM

FIG. 23



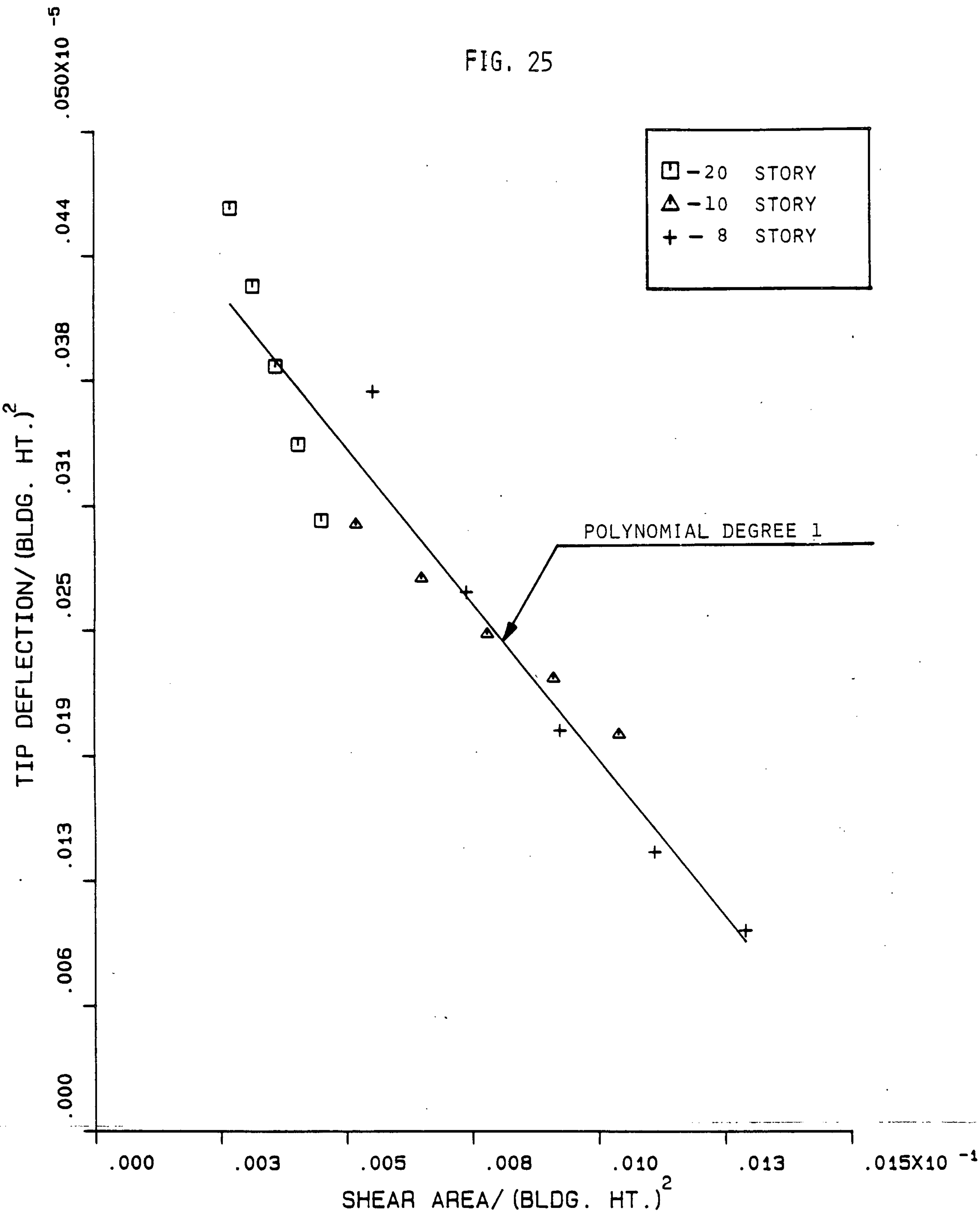
SCATTER DIAGRAM

FIG. 24



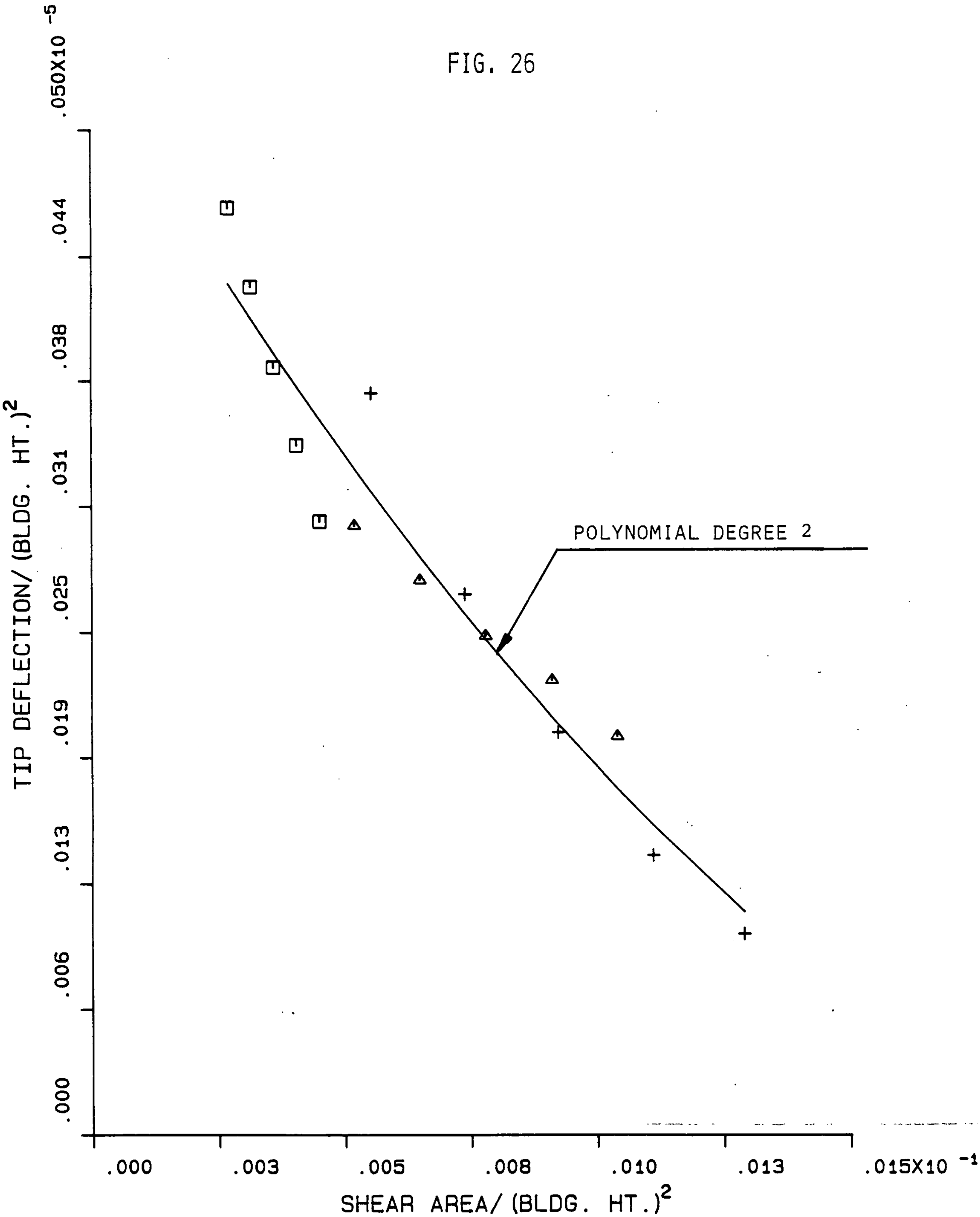
SCATTER DIAGRAM

FIG. 25



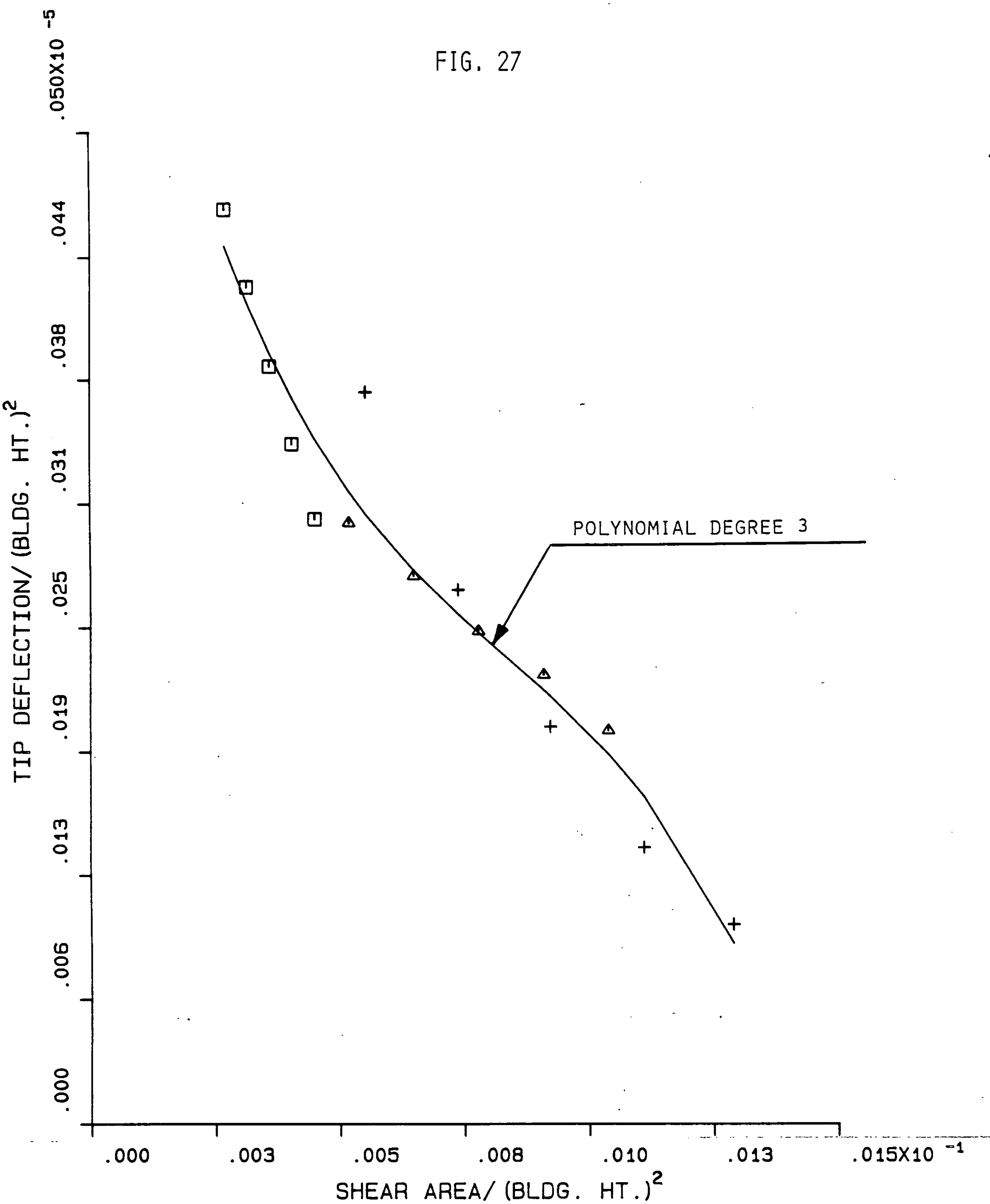
SCATTER DIAGRAM

FIG. 26



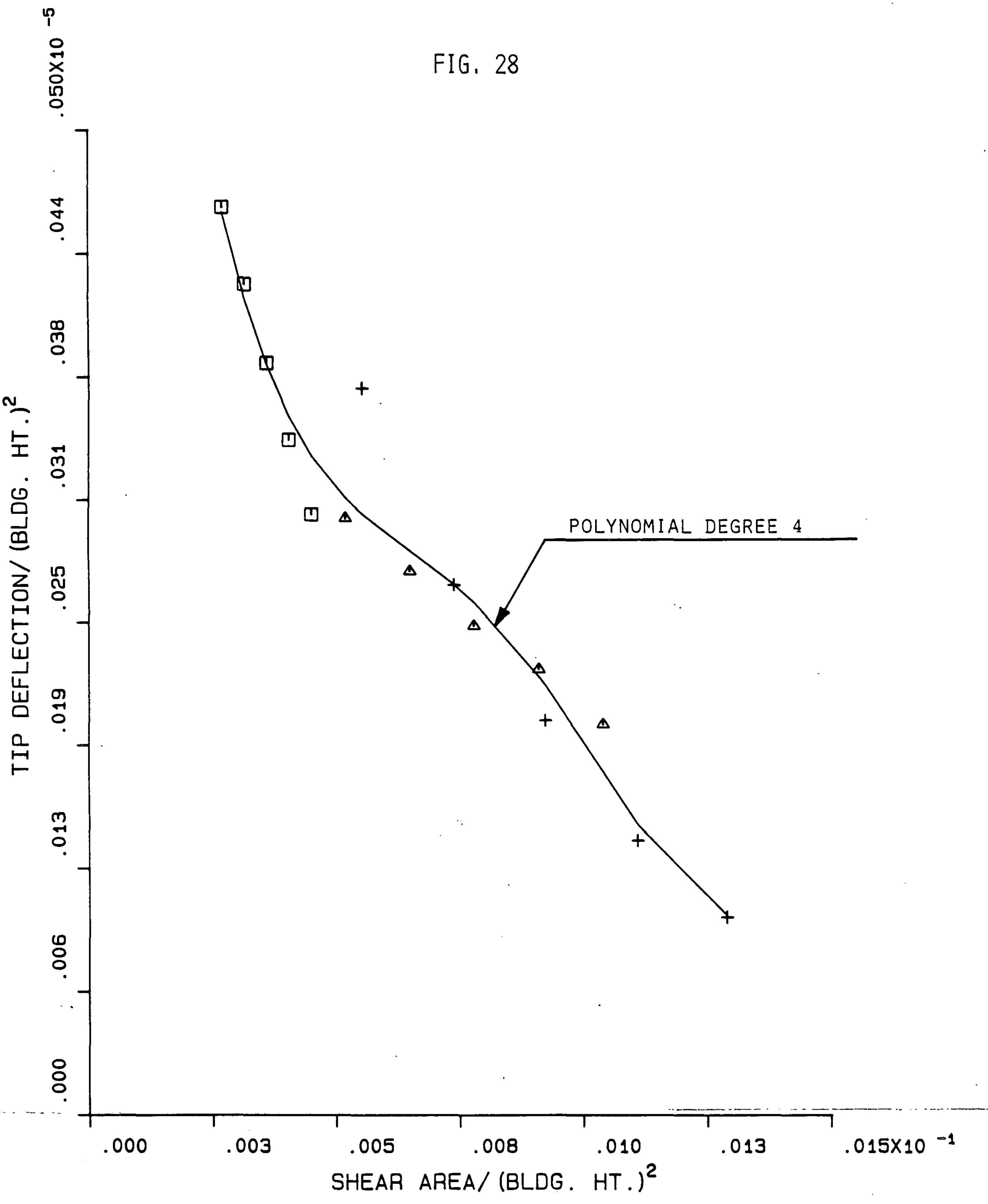
SCATTER DIAGRAM

FIG. 27



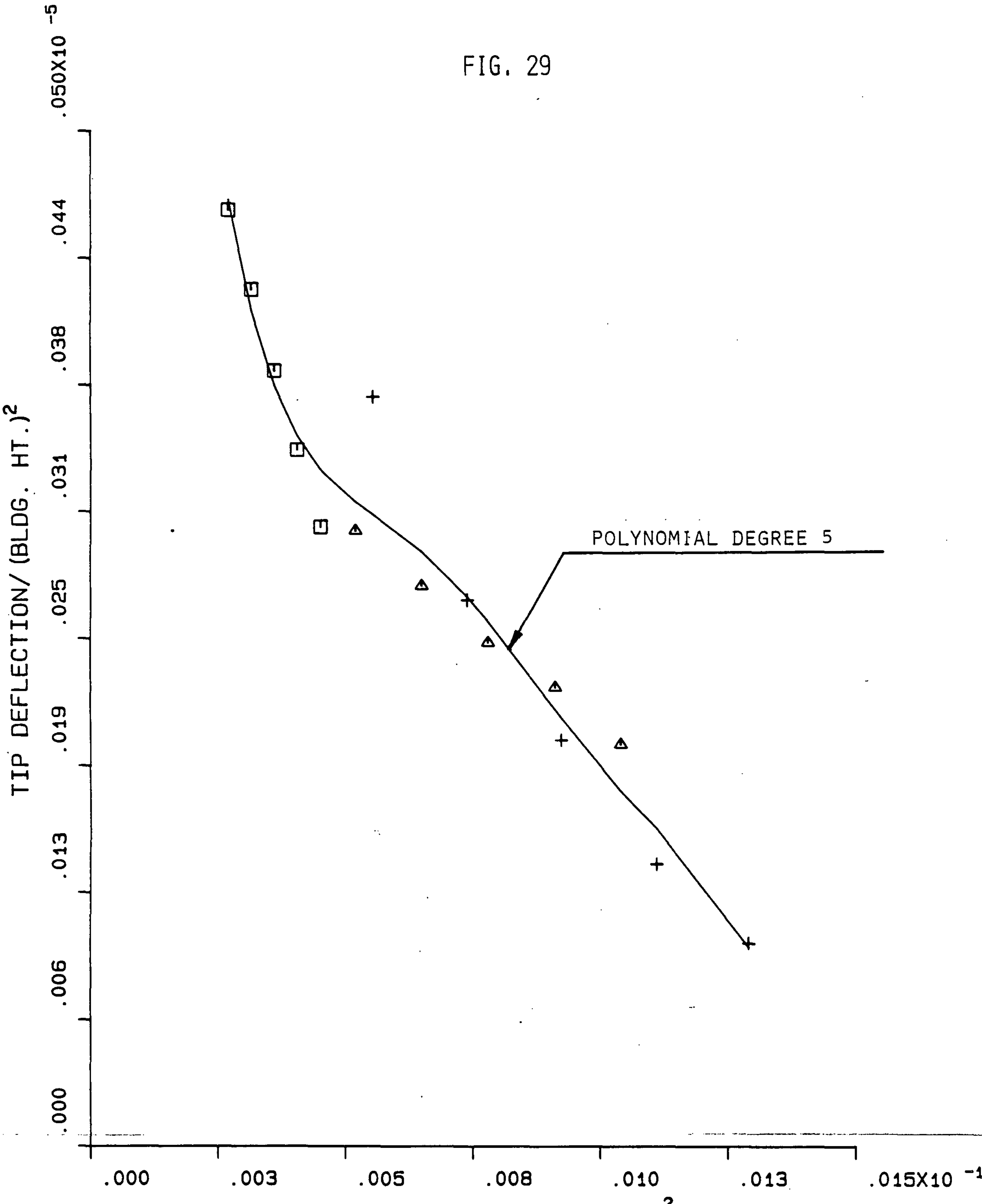
SCATTER DIAGRAM

FIG. 28



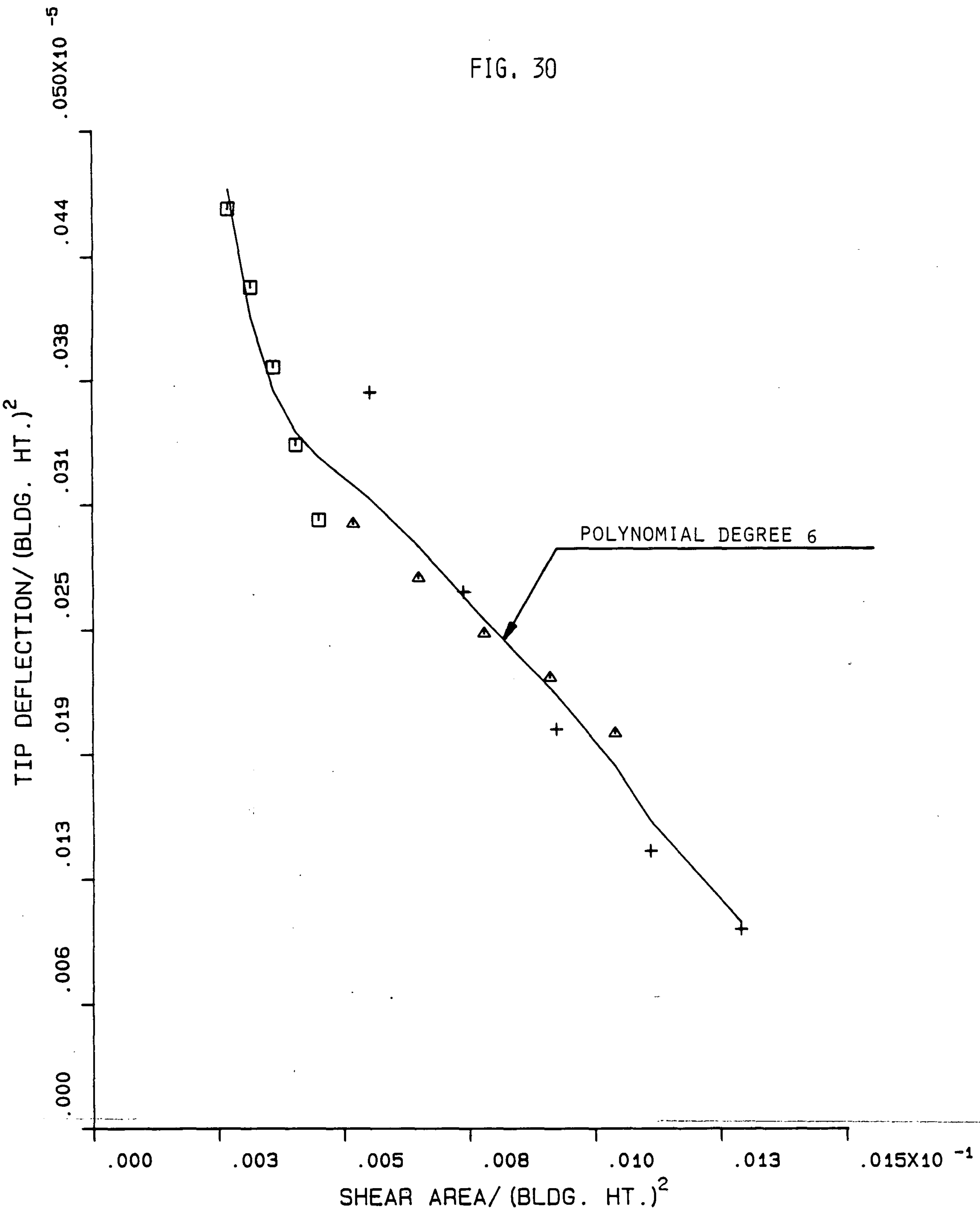
SCATTER DIAGRAM

FIG. 29



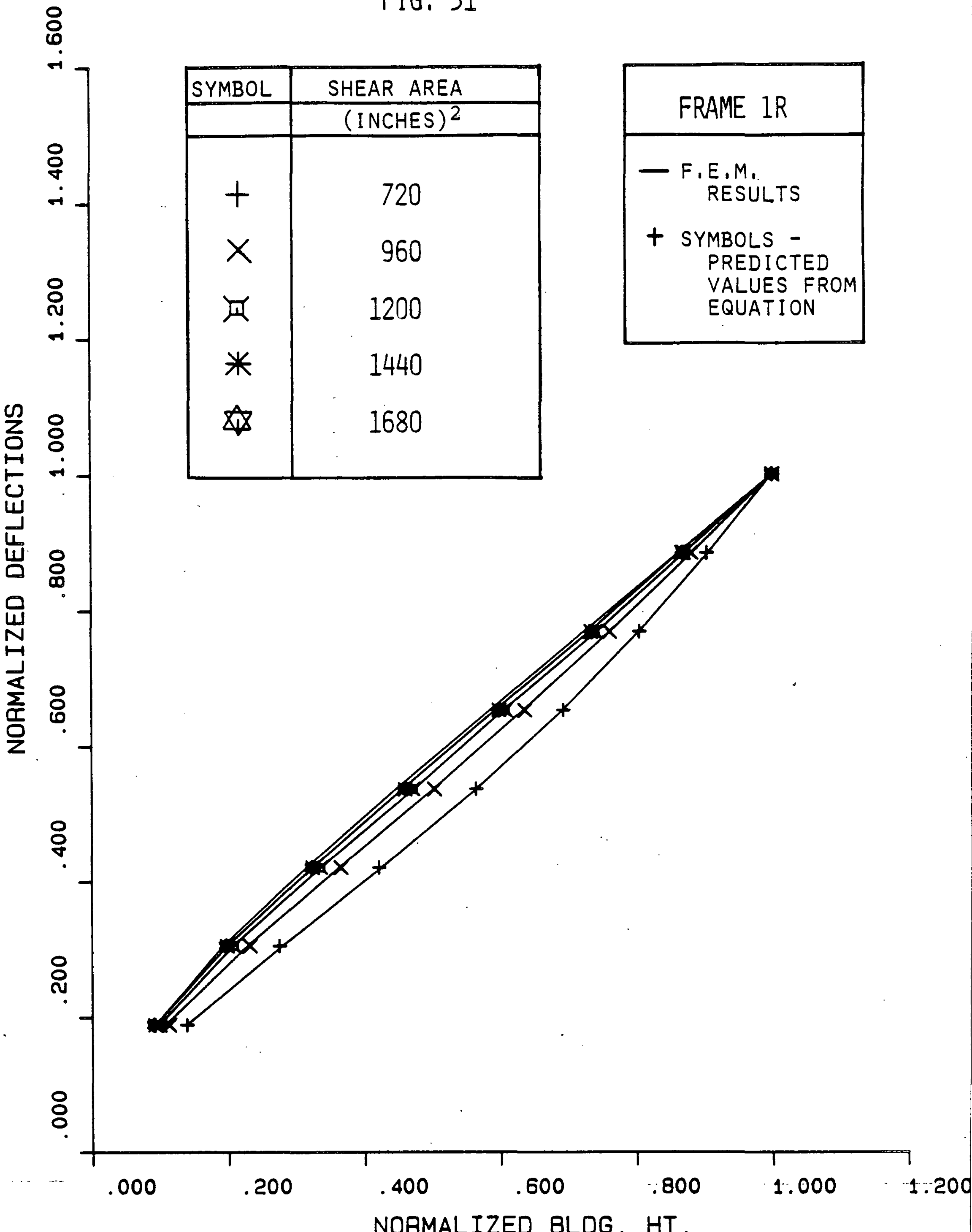
SCATTER DIAGRAM

FIG. 30



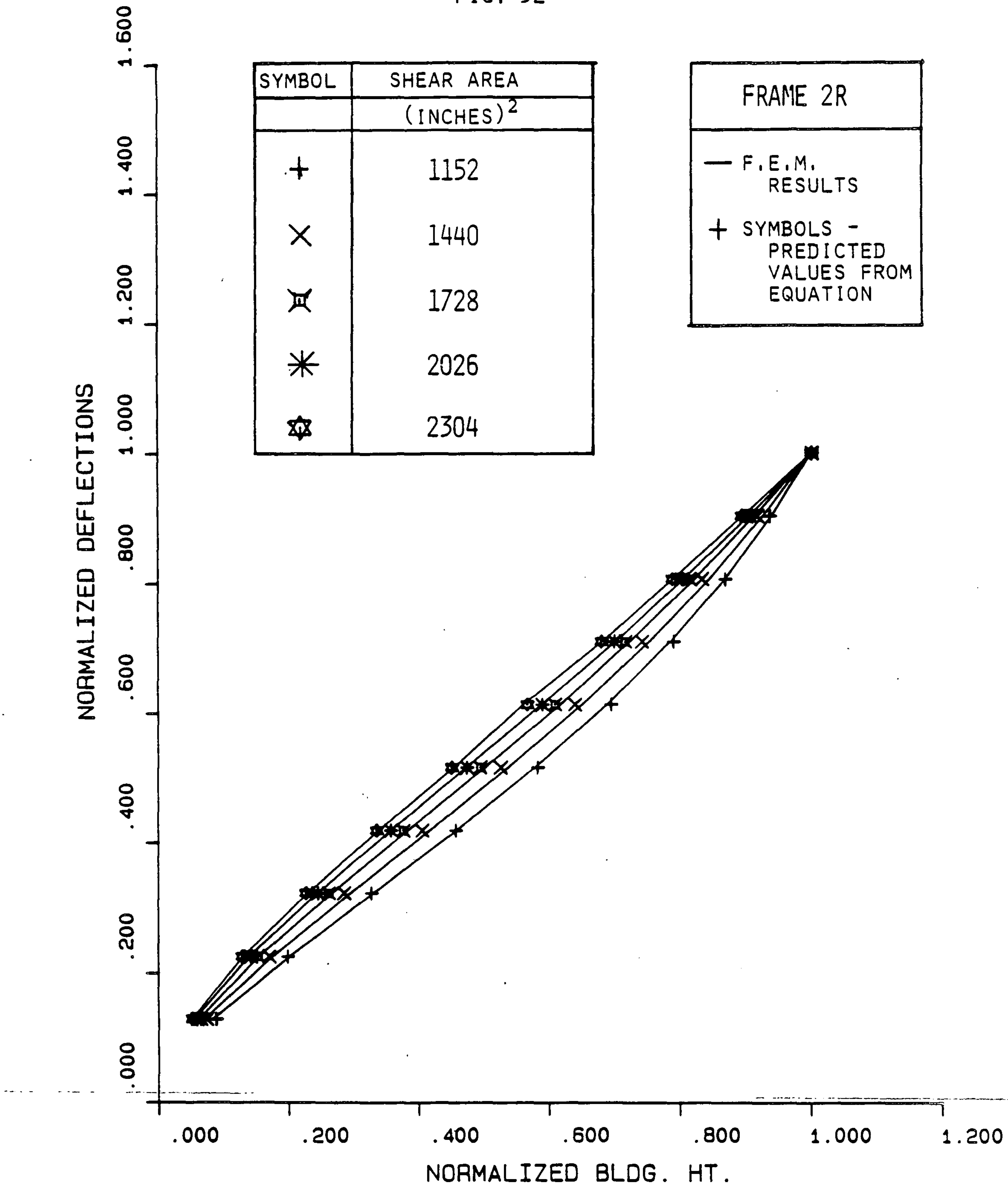
SCATTER DIAGRAM

FIG. 31



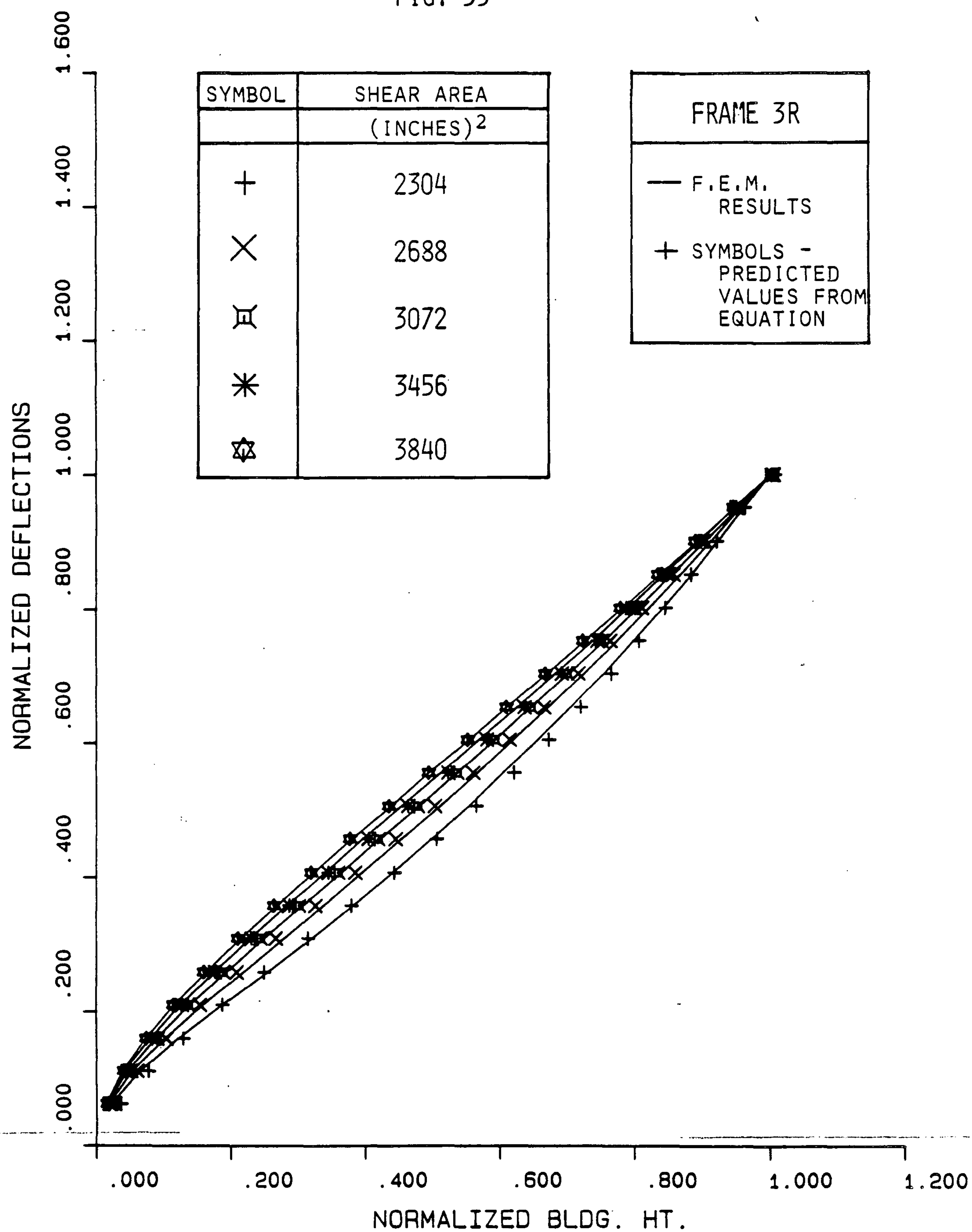
SYMBOL
SHEAR AREA (INCHES)^2
720
960
1200
1440
1680
FRAME 1R
F.E.M. RESULTS
SYMBOLS - PREDICTED VALUES FROM EQUATION
NORMALIZED DEFLECTIONS
.000
.200
.400
.600
.800
1.000
1.200
1.400
1.600
NORMALIZED BLDG. HT.
.000
.200
.400
.600
.800
1.000
1.200

FIG. 32



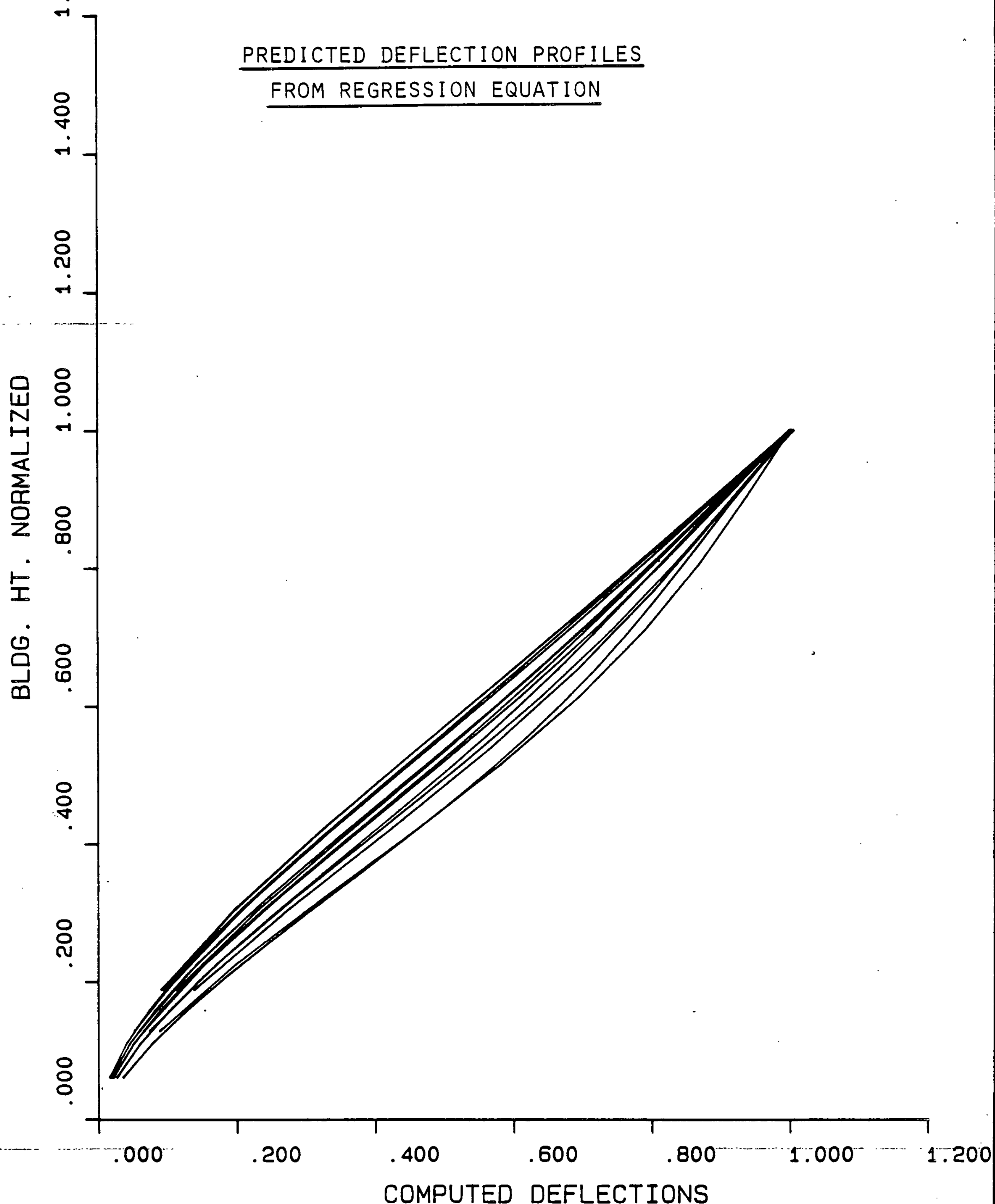
SYMBOL
SHEAR AREA
(INCHES)^2
1152
1440
1728
2026
2304
FRAME 2R
F.E.M. RESULTS
SYMBOLS - PREDICTED VALUES FROM EQUATION
NORMALIZED DEFLECTIONS
NORMALIZED BLDG. HT.
.000
.200
.400
.600
.800
1.000
1.200
1.400
1.600

FIG. 33



SYMBOL
SHEAR AREA
(INCHES)2
2304
2688
3072
3456
3840
FRAME 3R
F.E.M. RESULTS
SYMBOLS - PREDICTED VALUES FROM EQUATION
NORMALIZED DEFLECTIONS
.000
.200
.400
.600
.800
1.000
1.200
1.400
1.600
NORMALIZED BLDG. HT.
1.200

FIG. 34



PREDICTED DEFLECTION PROFILES
FROM REGRESSION EQUATION
BLDG. HT. NORMALIZED
.000
.200
.400
.600
.800
1.000
1.200
1.400
1.600
.000
.200
.400
.600
.800
1.000
1.200
COMPUTED DEFLECTIONS

REFERENCES

1. Fintel, Mark, Handbook of Concrete Engineering, Van Nostrand Reinhold Company, New York, 1974.

2. Derecho, A. T., "Frames and Frame-Shear Wall Systems", American Concrete Institute, Special Publication, ACI-Sp-36, pp. 13-39, Detroit, 1973.

3. Khan, F. R. and Iyengar, H. S., "Optimization Approach for Concrete High-Rise Structures", American Concrete Institute, Special Publication, ACI Sp-36, pp. 61-74, Detroit, 1973.

4. ACI Committee 442, "Response of Buildings to Lateral Forces", ACI Journal Proceedings, 68(2), 81-106, Feb., 1971.

5. Popoff, A., Jr., "What Do We Need To Know About The Behavior of Structural Concrete Shearwall Systems", American Concrete Institute, Special Publication, ACI-Sp-36, pp. 1-14, Detroit, 1973.

6. Notch, J. M. and Kostem, C. N., "Interaction of Frame-Shearwall Systems Subject to Lateral Loadings", Fritz Engineering Laboratory Report No. 354.443, Lehigh University, 1976.

7. International Conference of Building Officials, "Uniform Building Code", Whittier, California, 1982.

8. Applied Technology Council, "Tentative Provisiions for the Developement of Seismic Regulations for Buildings", Publication ATC 3-06, San Francisco, California, 1978.

9. Structural Engineers Association of California, "Recommended Lateral Force Requirements and Commentary", San Francisco, California, 1967.

10. Dart, D. G. and Kirk, W. D., "Multistory Reinforced Concrete Building Design", M.S. Thesis, Department of Civil Engineering, Royal Military College of Canada, Kingston, Ontario, August 1982.

11. Khan, F. H. and Sbarounis, J. A., "Interaction of Shear Walls and Frames", Proceedings, ASCE 90 (ST-3), 285-335, June 1964.

12. MacLeod, I.A., "Shear Wall-Frame Interaction - A Design Aid", Portland Cement Associaton, 1970.

13. ACI Committee 435, "Allowable Deflections", ACI Journal, Proceedings, 65(31), 433-444, June 1968.

14. Parme, A.L., "Design of Combined Frames and Shear Walls", TALL BUILDINGS, Pergamon Press Limited, London, 1967, pp. 291-320.

15. Gould, P.L., "Interaction of Shear Wall-Frame Systems in Multistory Buildings", ACI Journal, Proceedings V. 62, No. 1, Jan. 1965, pp. 45-70.

16. Rosenblueth, E. and Holtz, I., "Elastic Analysis of Shear Walls in Tall Buildings", ACI Journal, Proceedings, V. 56, No. 12, June 1960, pp.1209-1222.

17. Cardin, B., "Concrete Shear Walls Combined with Rigid Frames in Multi-Story Buildings Subjected to Lateral Loads", ACI Journal, Proceedings

18. Rosman, R., "Laterally Loaded Systems Consisting of Walls and Frames", TALL BUILDINGS, Pergamon Press Limited, London, 1967, pp. 273-289.

19. Derecho, A. T., "Analysis of Plane Multistory Frame Shear Wall Structures Under Lateral and Gravity Loads", User's Manual, Portland Cement Association, 1971.

20. Zagajeski, S. W. and Bertero, V. V., "Computer-Aided Optimum Seismic Design of Ductile Reinforced Concrete Moment-Resisting Frames", Earthquake Engineering Research Center (EERC), University of California, Berkeley, California, 1977.

21. Clough, R. W. and Benuska, K. L., "FHA Study of Seismic Design Criteria for High-Rise Buildings", A report prepared for the Technical Studies Program of the Federal Housing Administraon, HUD TS-3, 1966.

22. Areiza, G. and Kostem, C. N., "Interaction of Reinforced Concrete Frame-Shear Wall Systems Subjected to Earthquake Loadings", Fritz Engineering Laboratory Report No. 433.4, July 1979.

23. Bathe, J.-J., Wilson, E. L. and Peterson, E., "SAP-IV - A Structural Analysis Program for Static and Dynamic Response of Linear Systems", Earthquake Engineering Research Center (EERC), University of California, Berkeley, California, 1974.

24. American Concrete Institute Standards, "Building Code Requirements for Reinforced Concrete", ACI-318-77, Detroit, 1977.

25. Devore, J. L., Probability & Statistics for Engineering and the Sciences, Brooks/Cole Publishing Company, Monterey, California, 1982.

26. Draper, N. R. and Smith, H., Applied Regression Analysis, John Wiley & Sons, New York, 1968.

27. Surahman, A., "Load Deformation Behavior of Various Component Elements of a Ship Hull Structure", Ph.D. Dissertation, Dept. of Civil Engineering, Lehigh University, 1984.

28. BMDP Statistical Software, Inc., 1964 Westwood Blvd., Berkeley, California. Copyright regents, University of California, (BMDP Prog. Revised, 1982).

A P P E N D I C E S

APPENDIX A

SCATTER DIAGRAM PLOTS

Scatter diagrams provide useful graphic information to determine if a strong relationship exists among the variables. The following figures show the plots for the 15 data points used. The points are designated as follows:

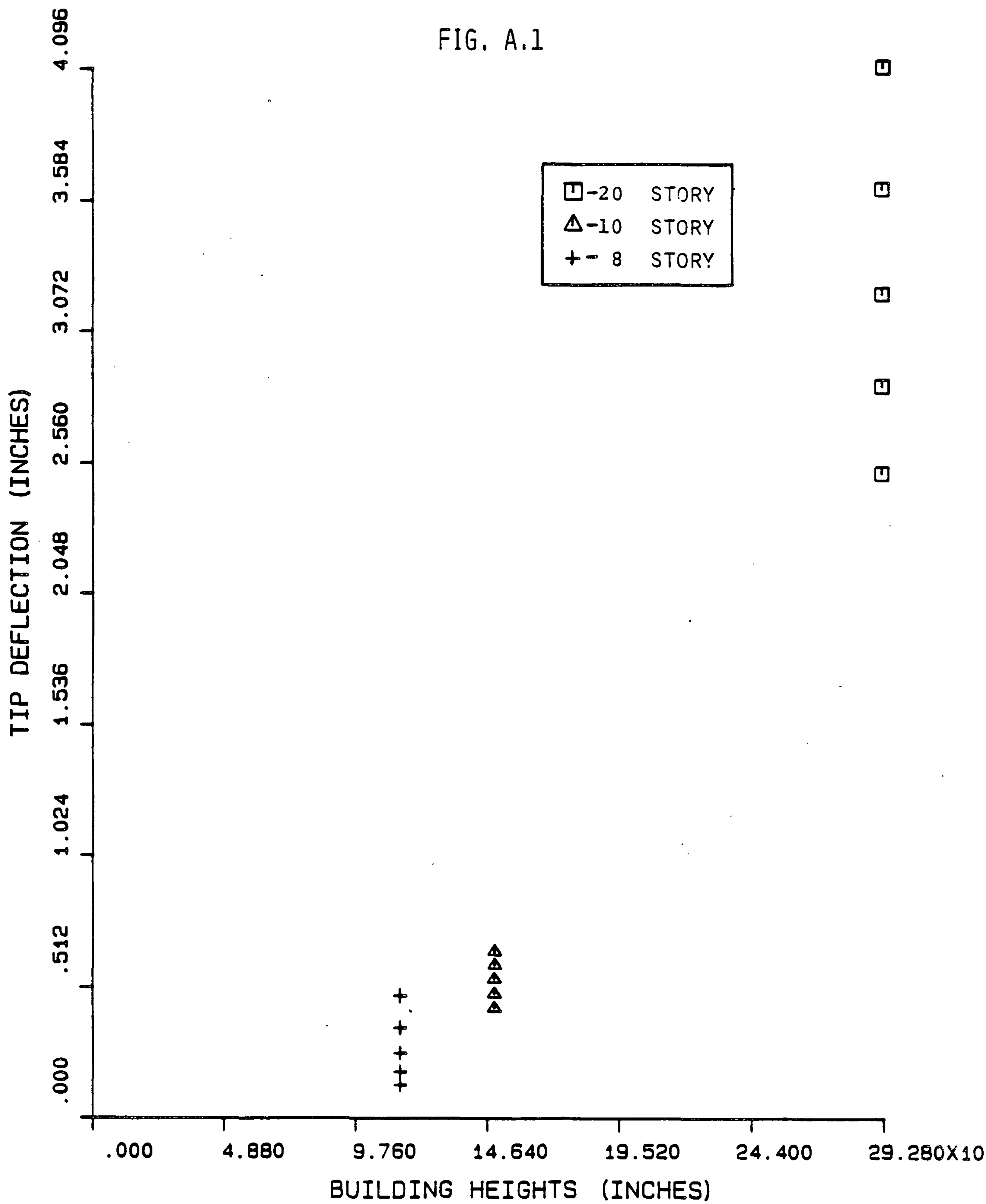
1. □ 20-Story Structure
2. △ 10-Story Structure
3. + 8-Story Structure

Figures A.1 through A.4 compare the following variables:

A.1 Deflection vs. Building Height
A.2 Deflection vs. Shear Wall Thickness
A.3 Deflection vs. Shear Area of Wall
A.4 Deflection vs. Shear Wall Length

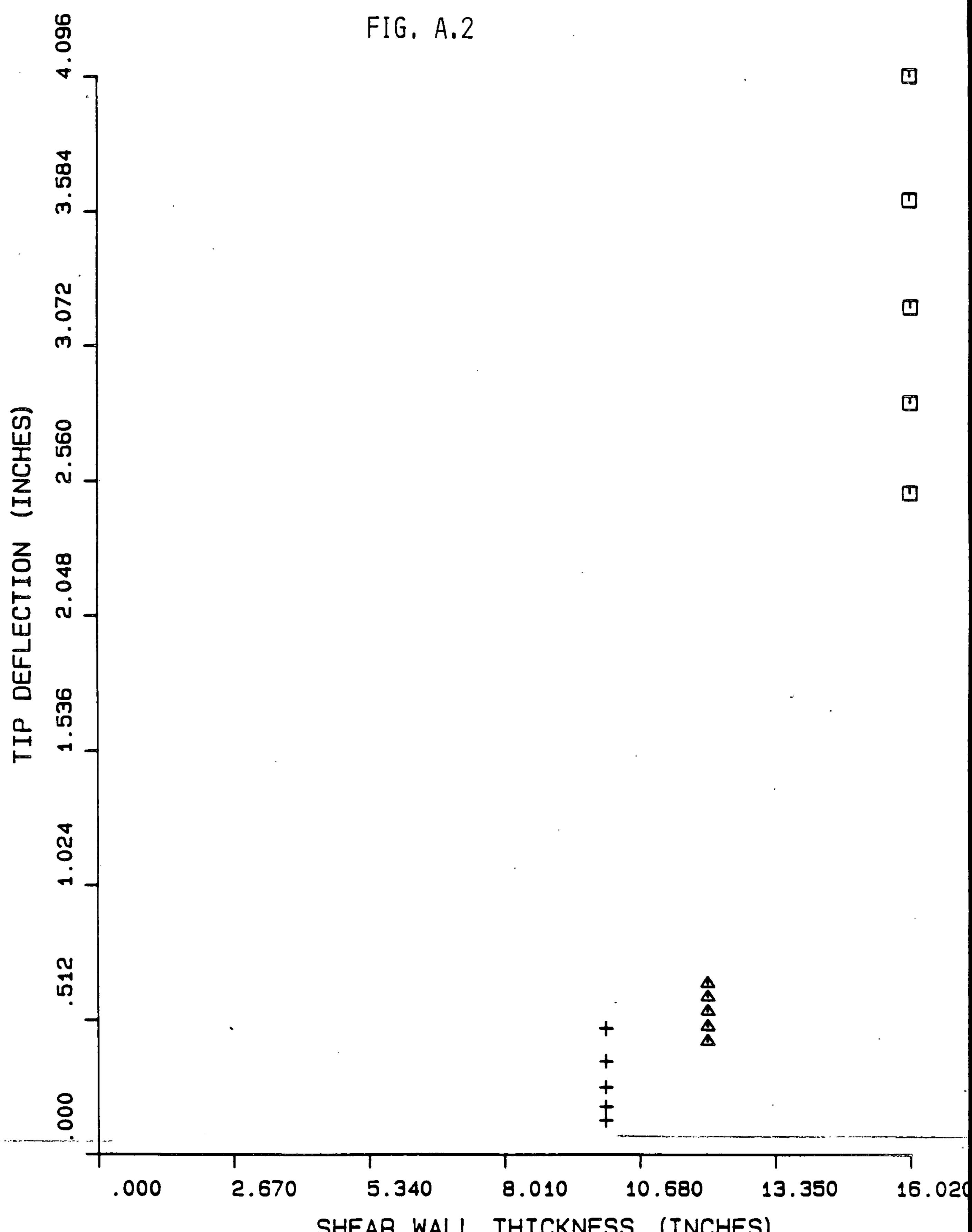
Figures A.5 through A.19 compare Tip Deflection/(Bldg. Ht.)^N vs. Shear Area/(Bldg. Ht.)^N with N varied from 1 to 3.

FIG. A.1



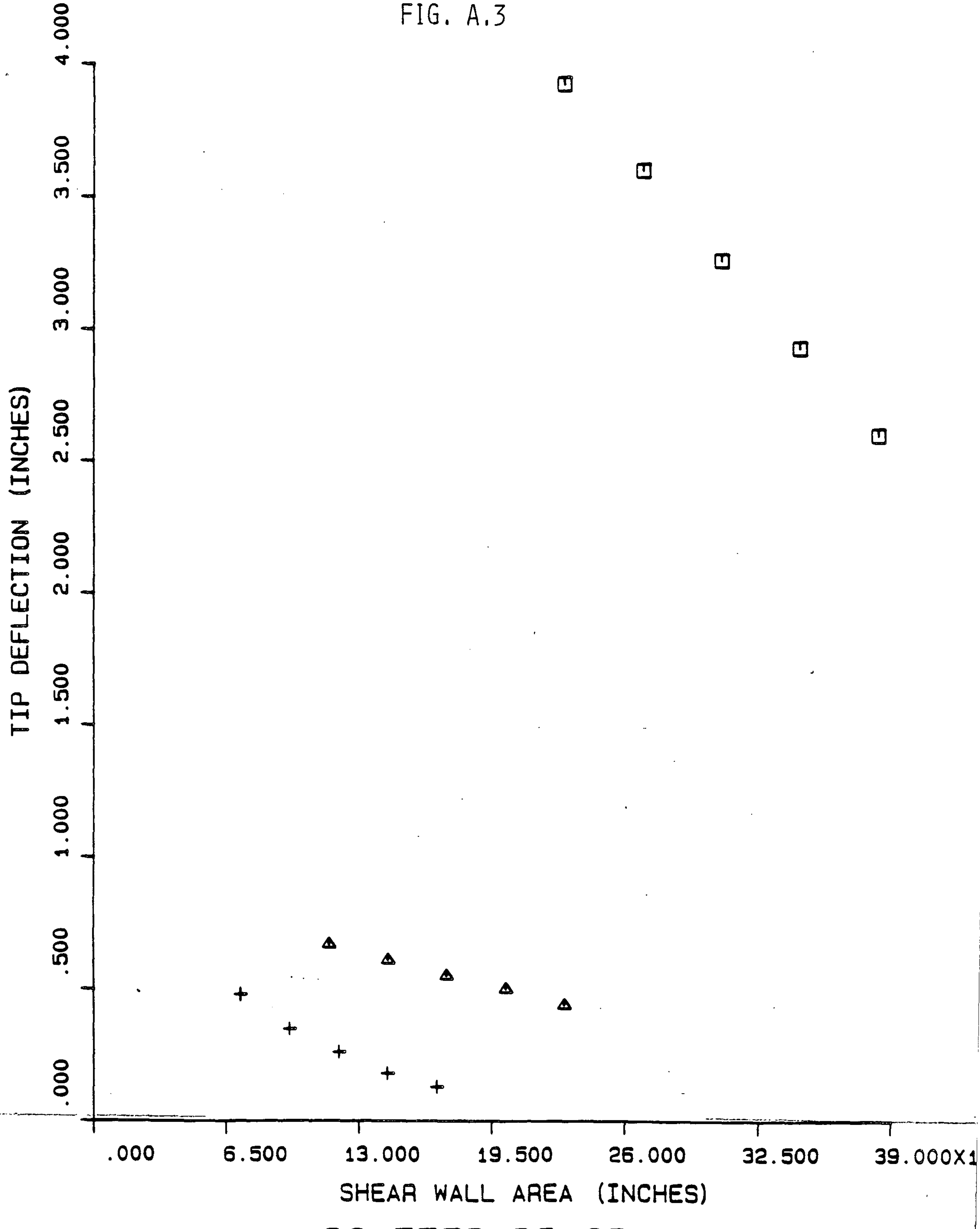
SCATTER DIAGRAM

FIG. A.2



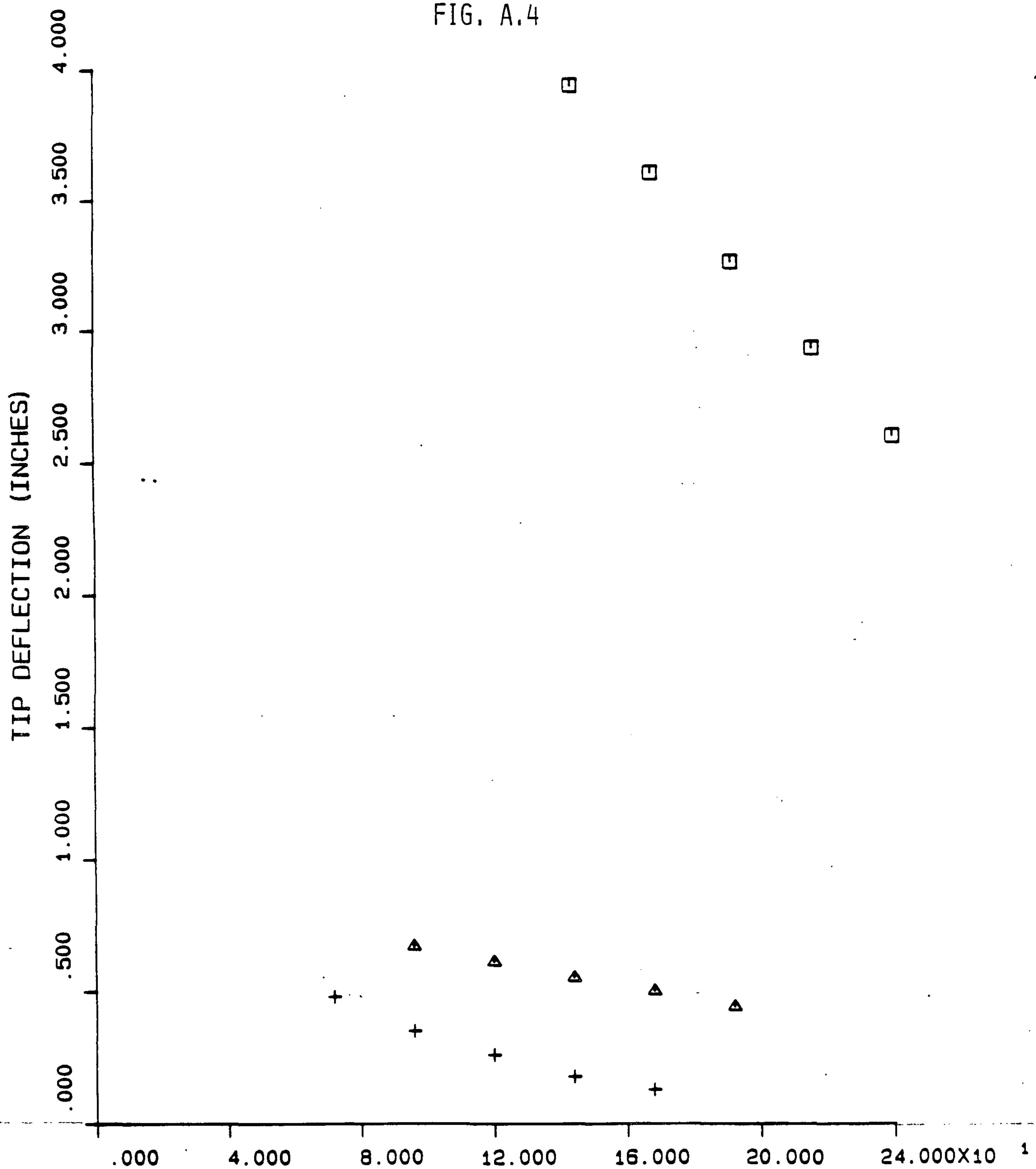
SCATTER DIAGRAM

FIG. A.3



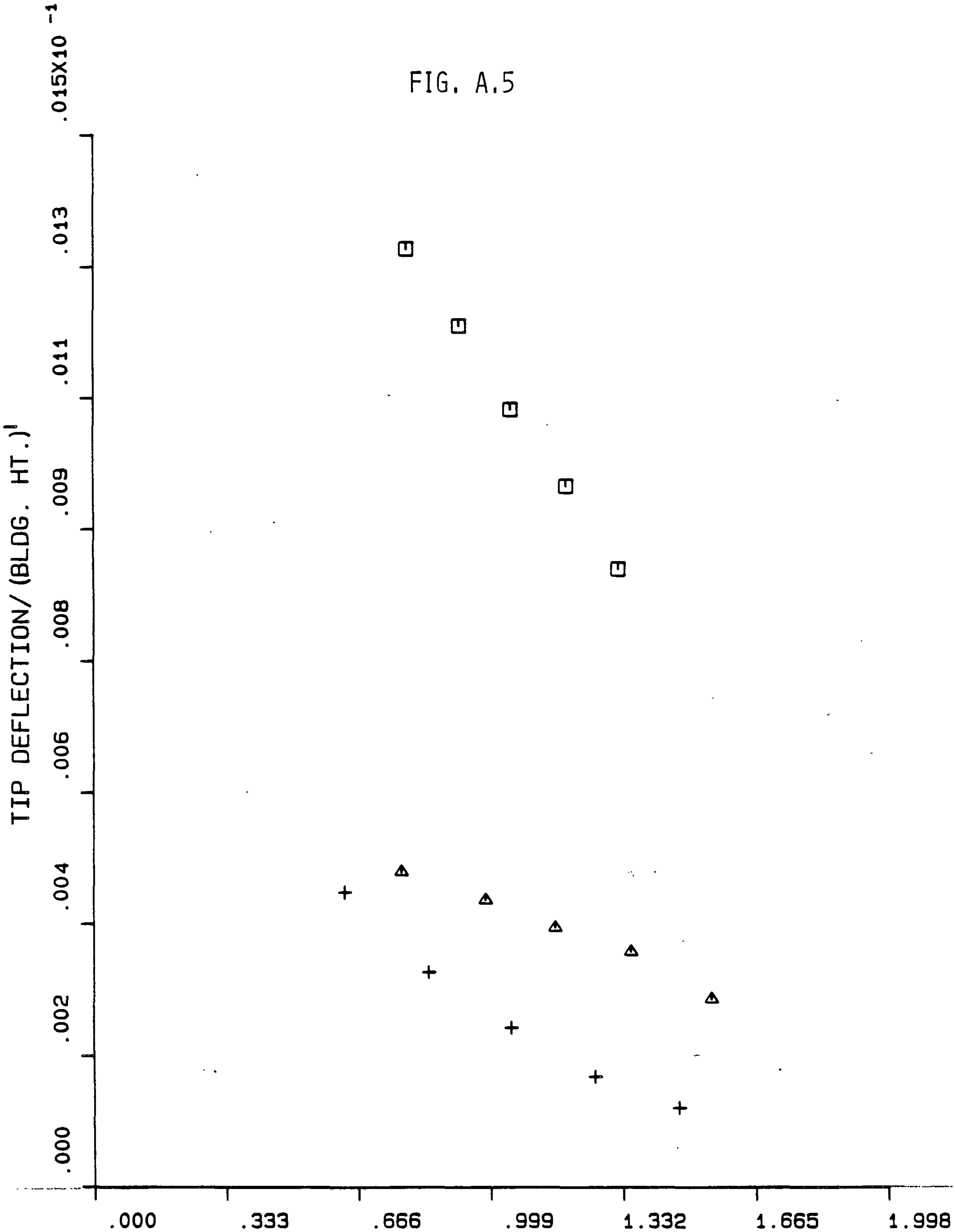
SCATTER DIAGRAM

FIG. A.4



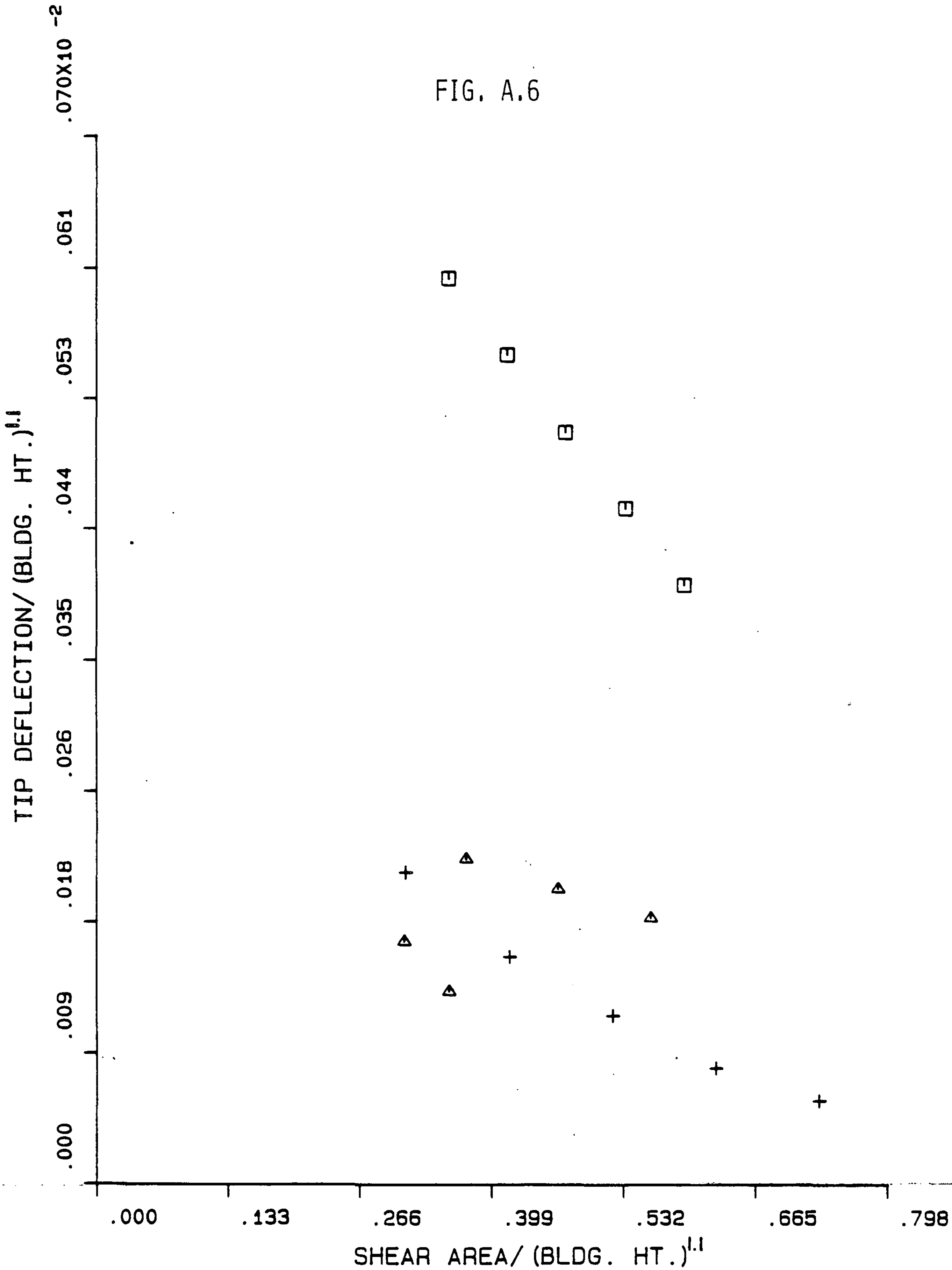
SCATTER DIAGRAM

FIG. A.5



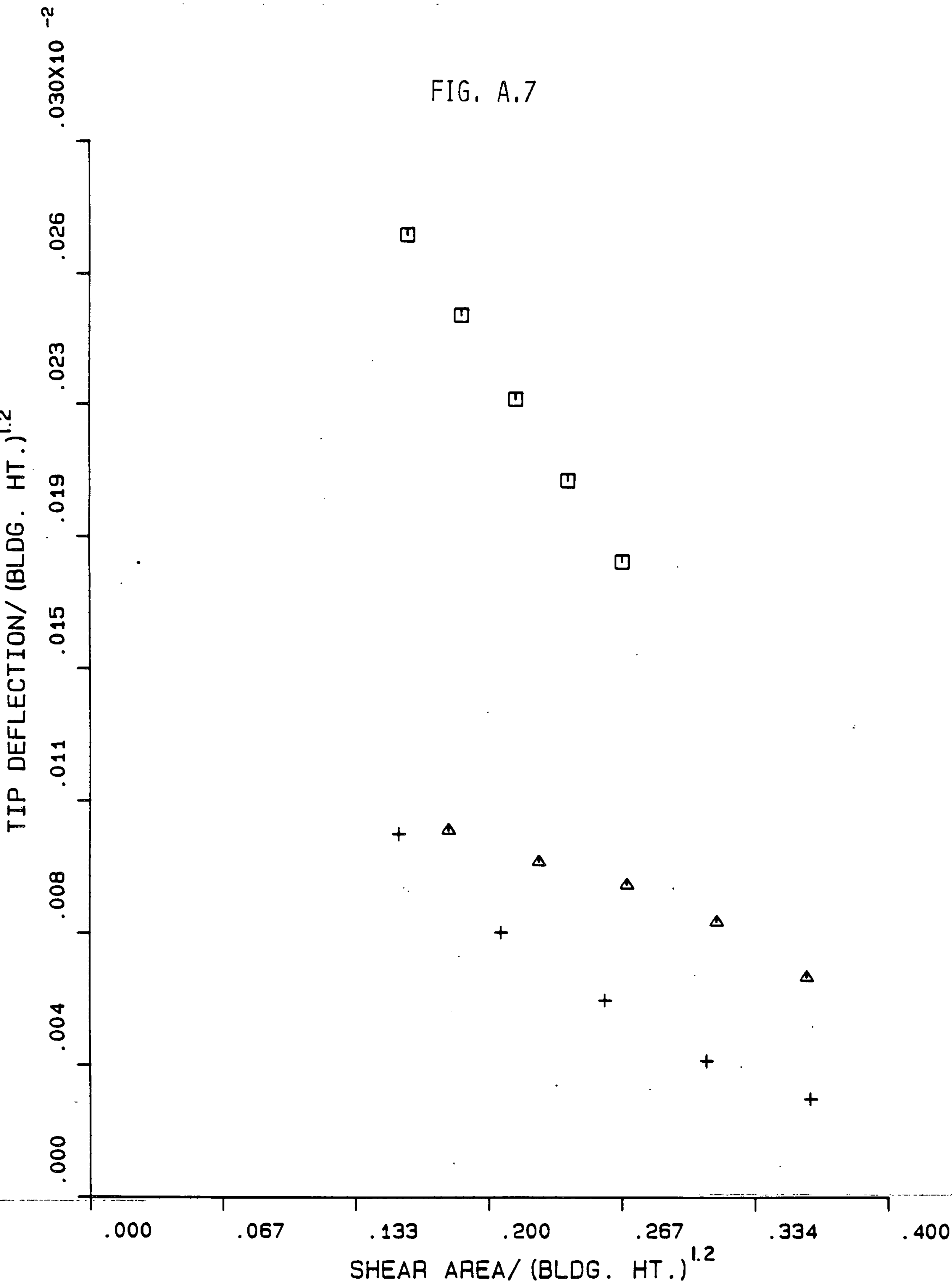
SCATTER DIAGRAM

FIG. A.6



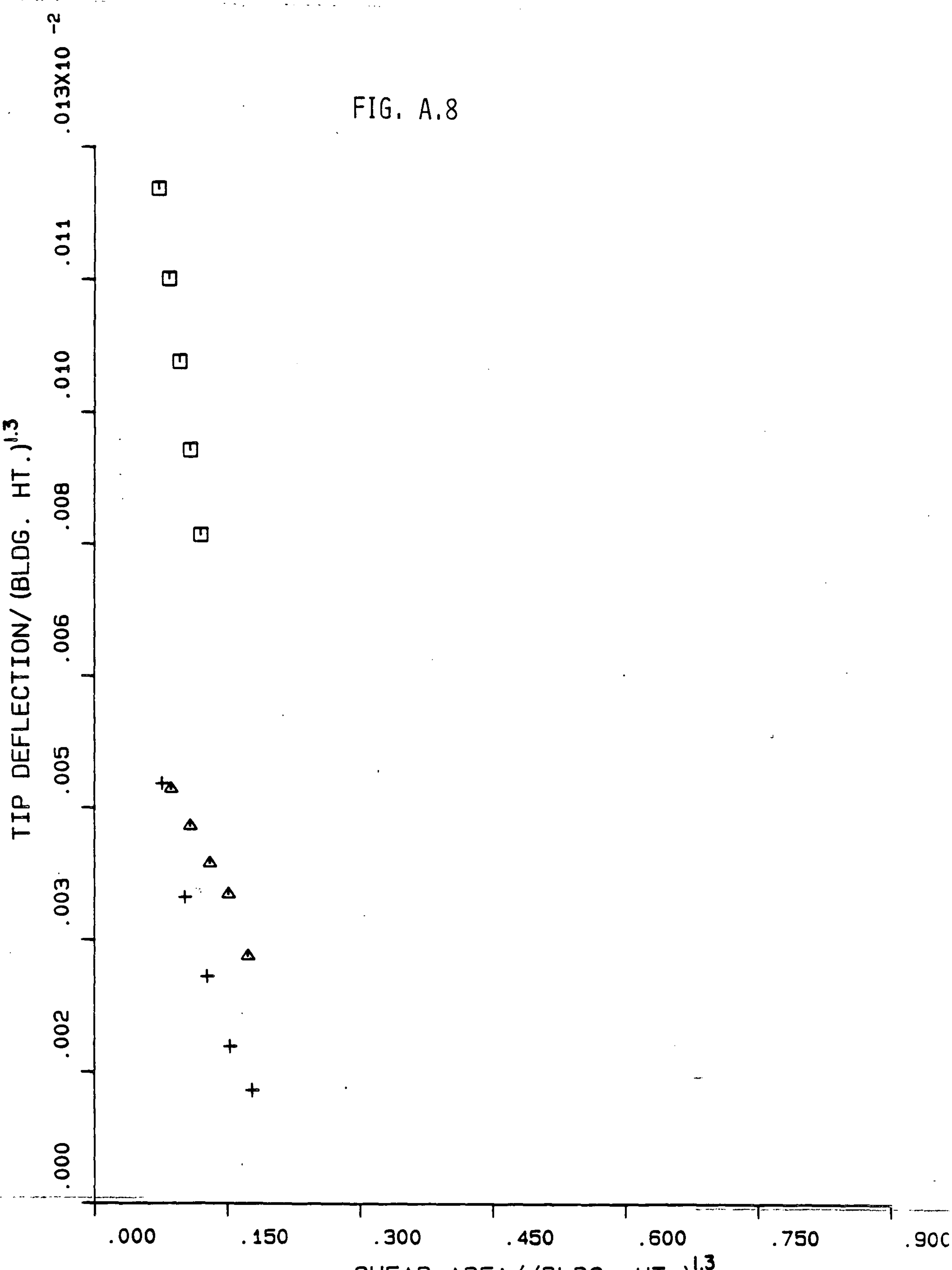
SCATTER DIAGRAM

FIG. A.7



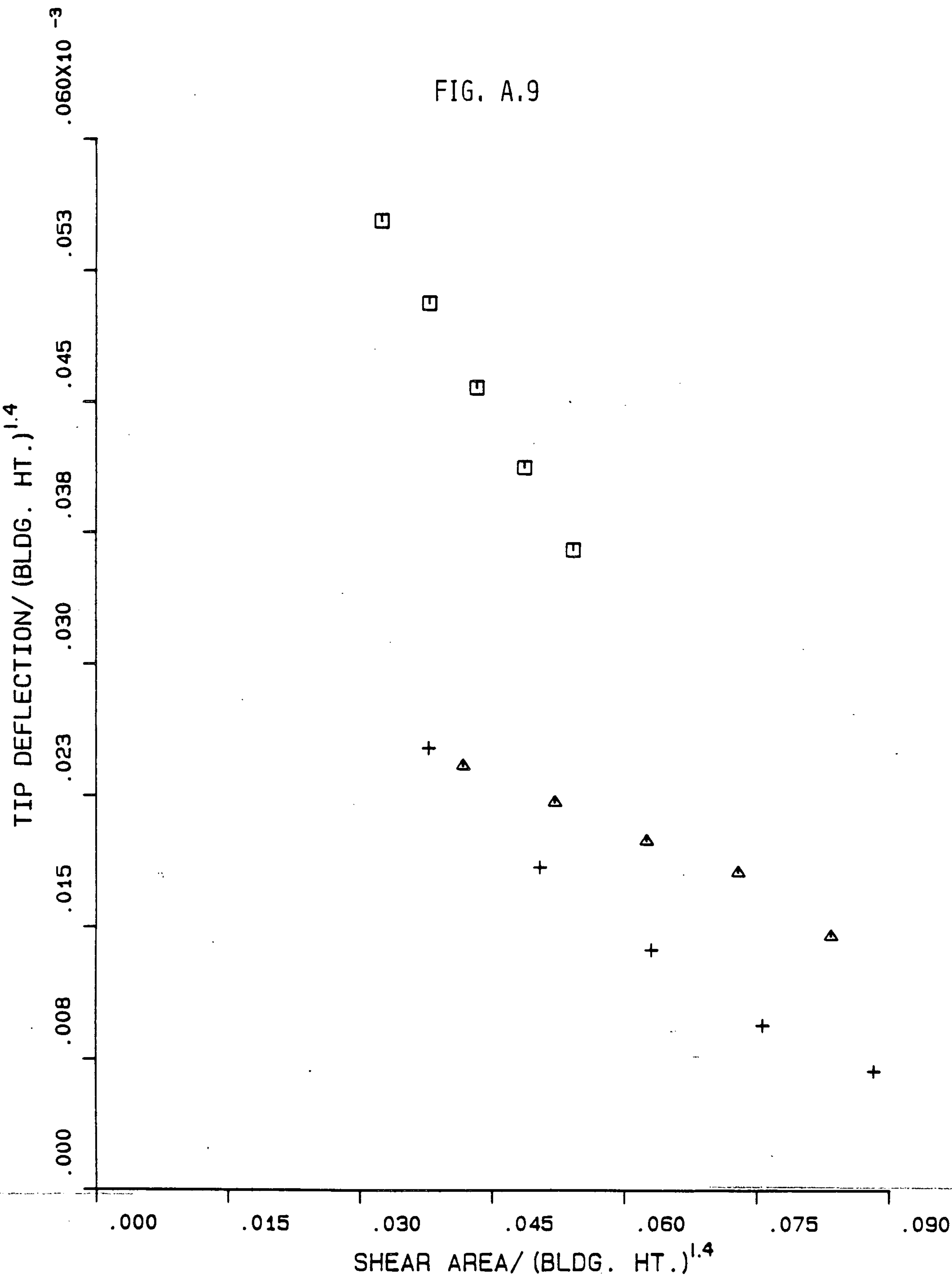
SCATTER DIAGRAM

FIG. A.8



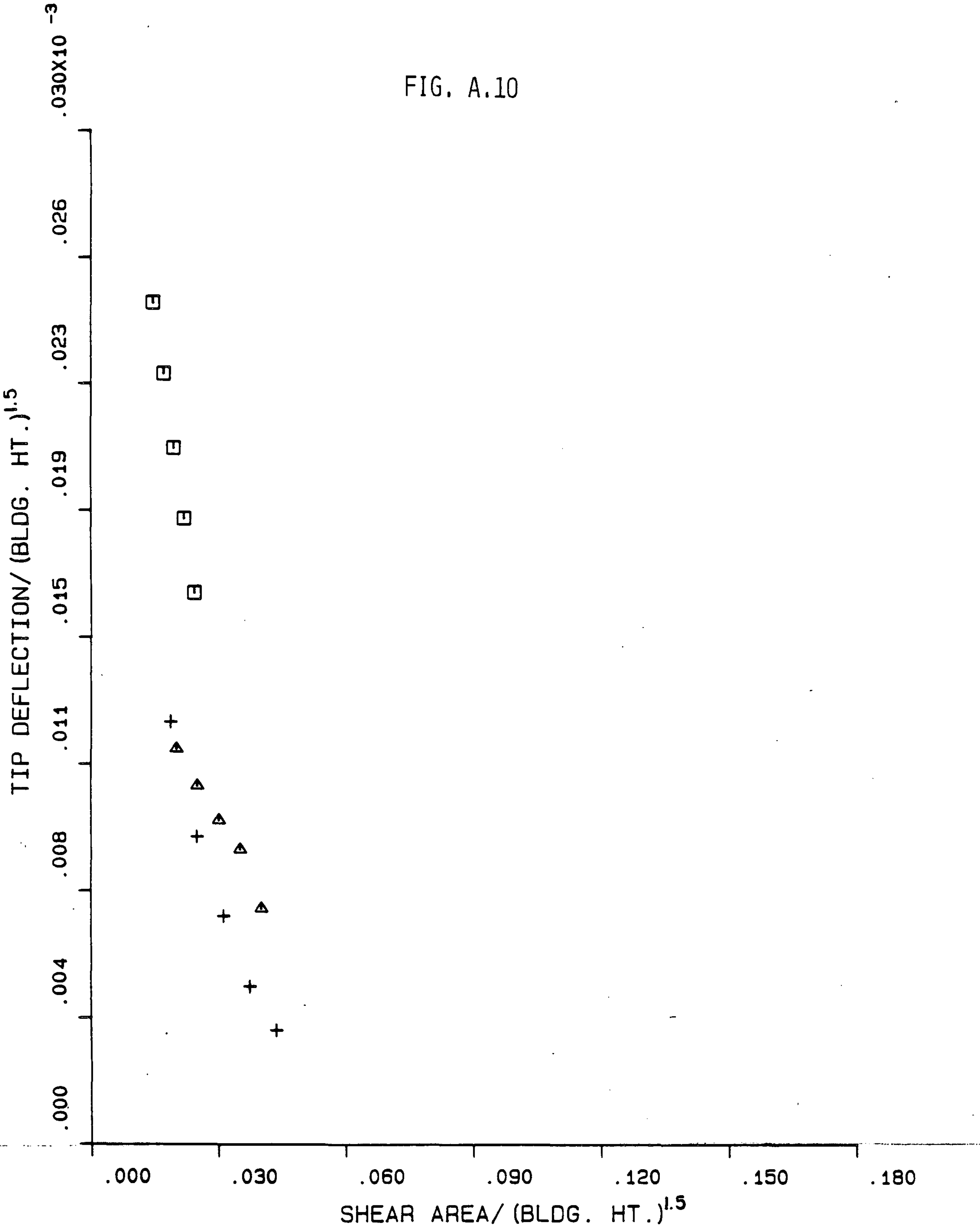
SCATTER DIAGRAM

FIG. A.9



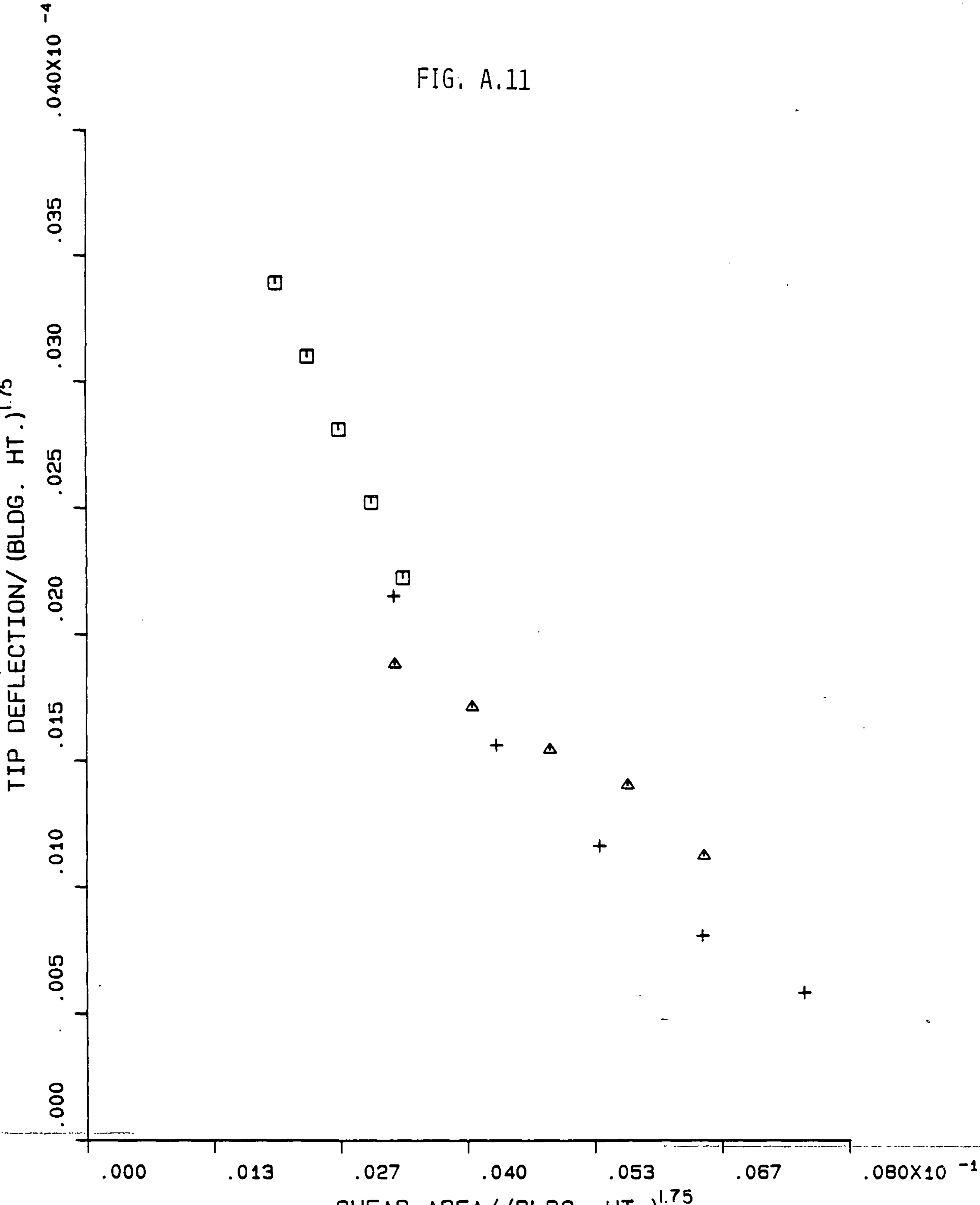
SCATTER DIAGRAM

FIG. A.10



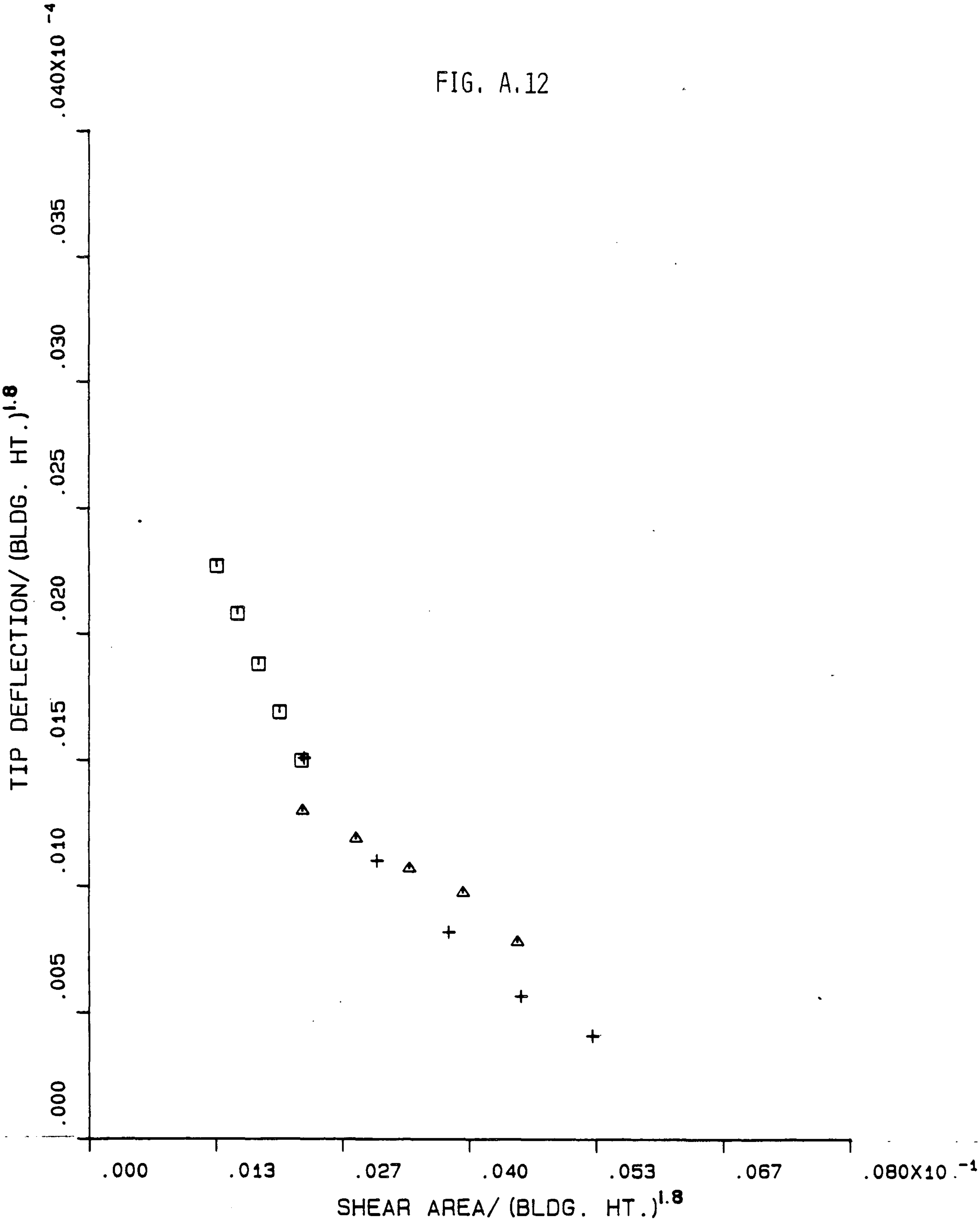
SCATTER DIAGRAM

FIG. A.11



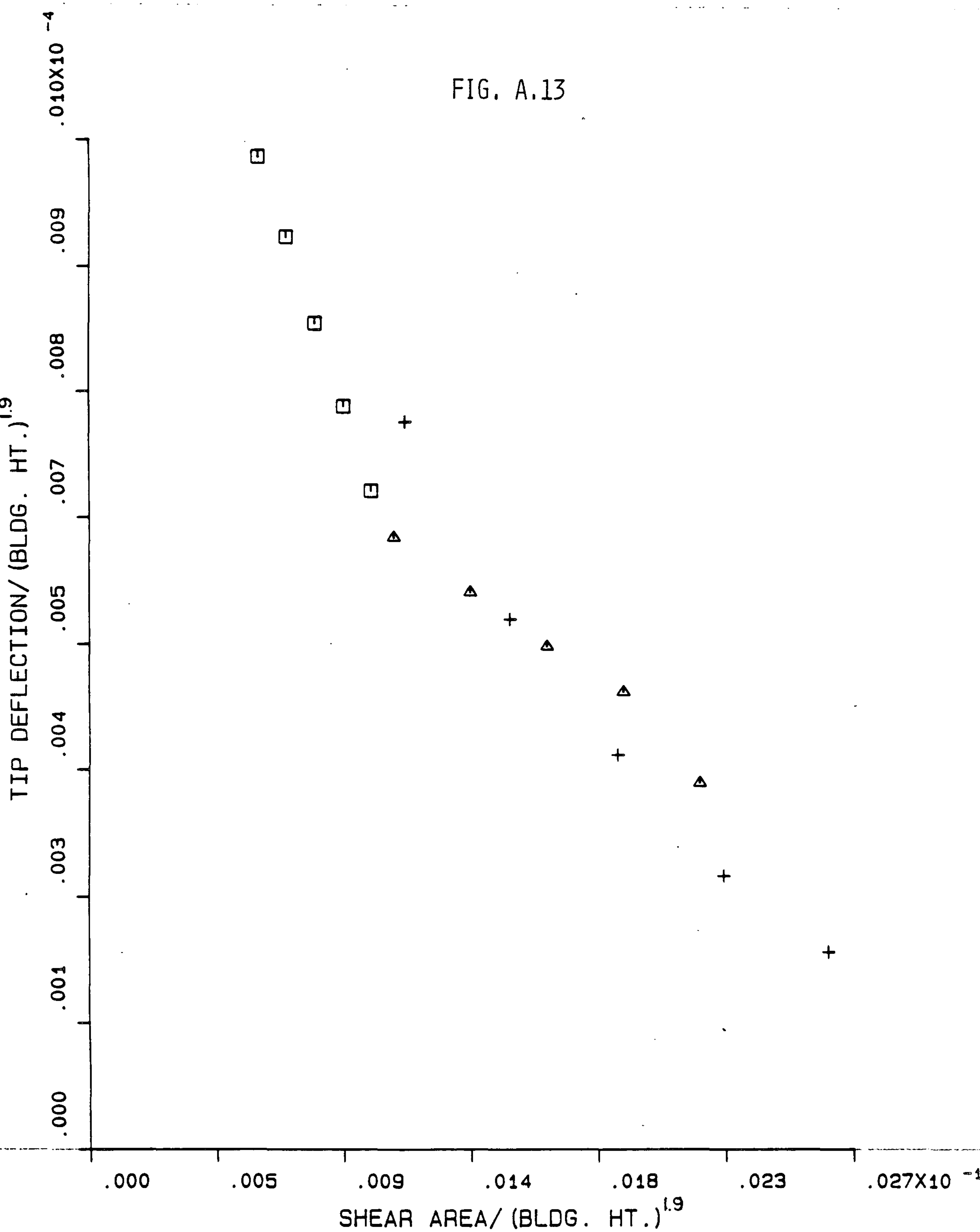
SCATTER DIAGRAM

FIG. A.12



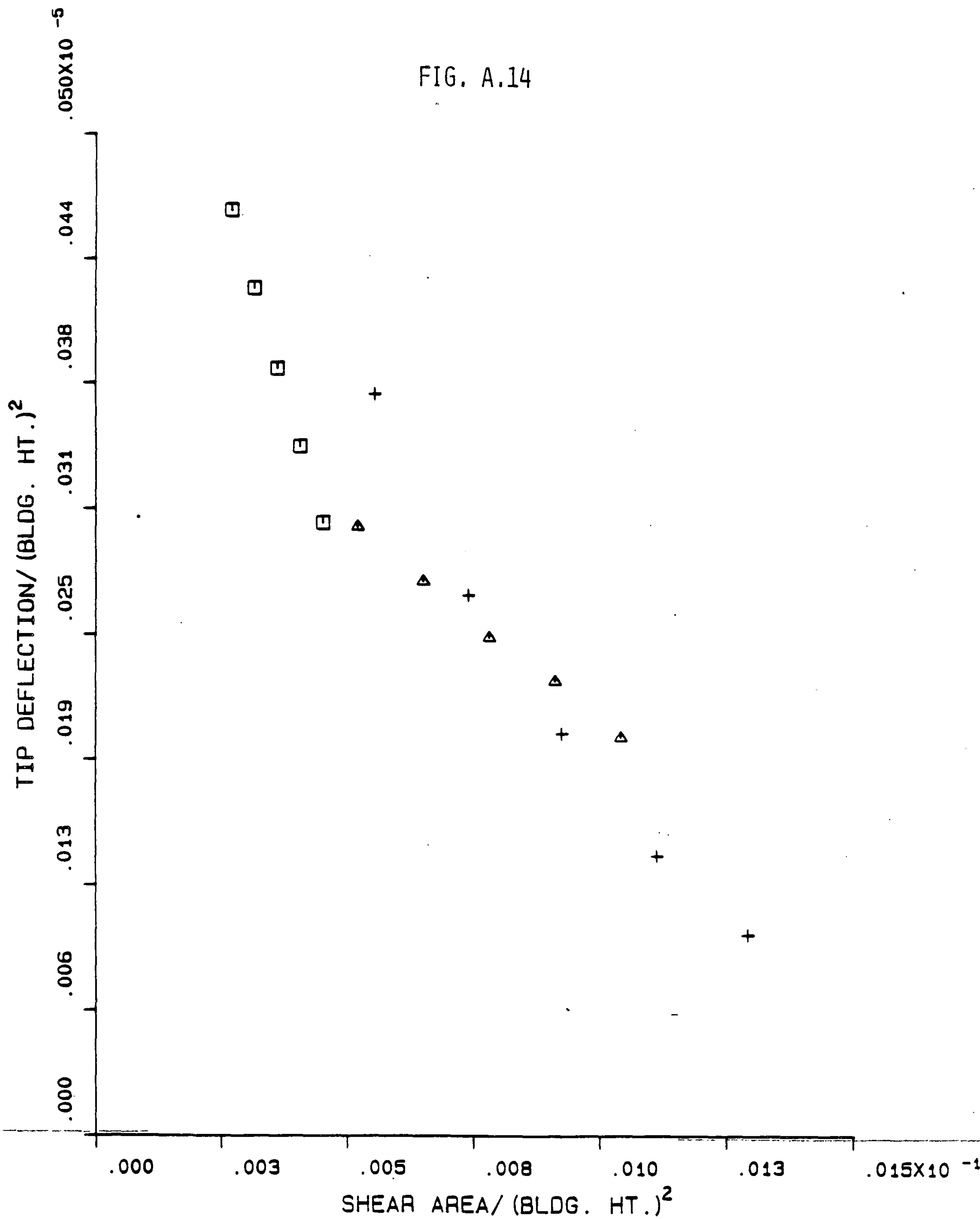
SCATTER DIAGRAM

FIG. A.13



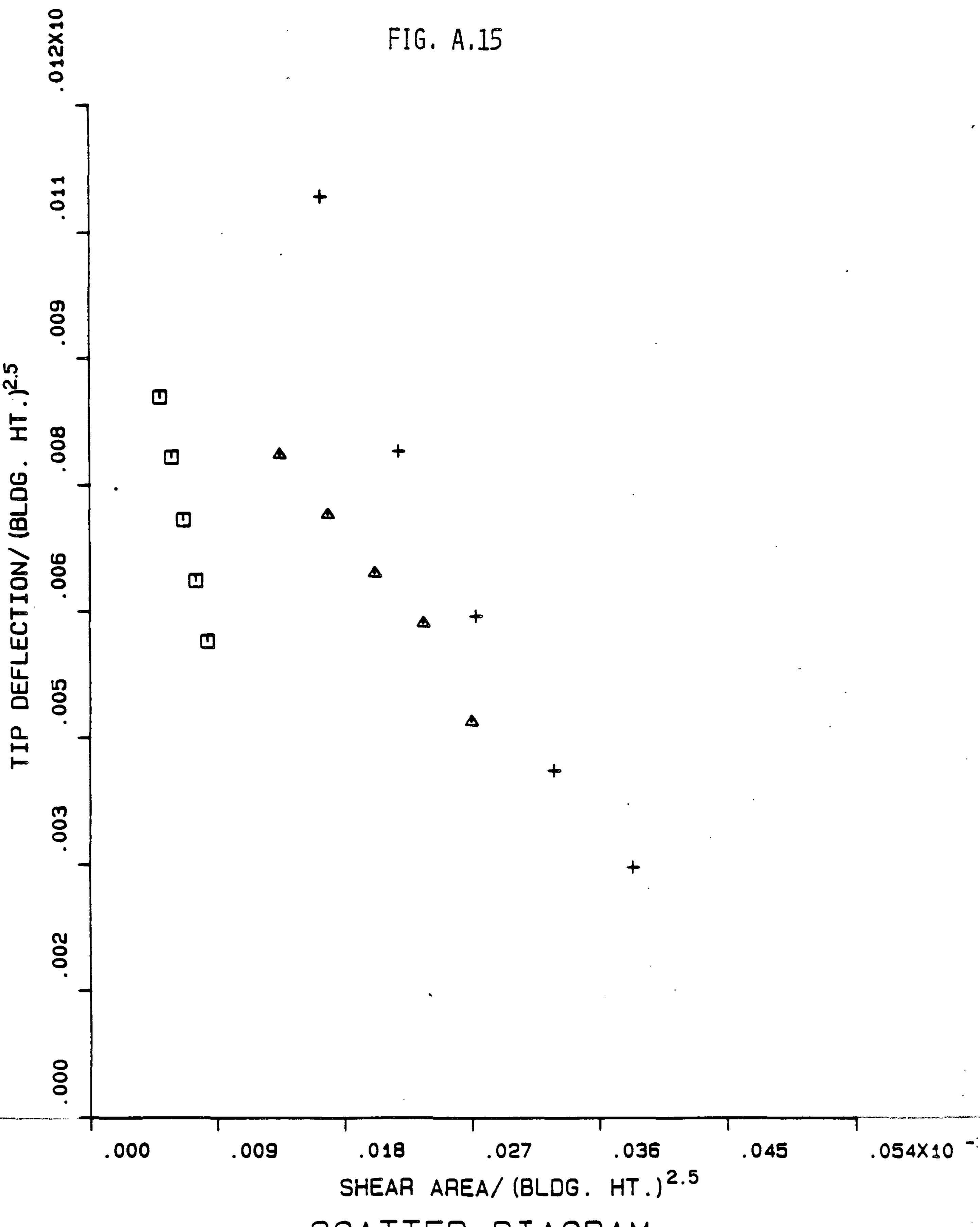
SCATTER DIAGRAM

FIG. A.14



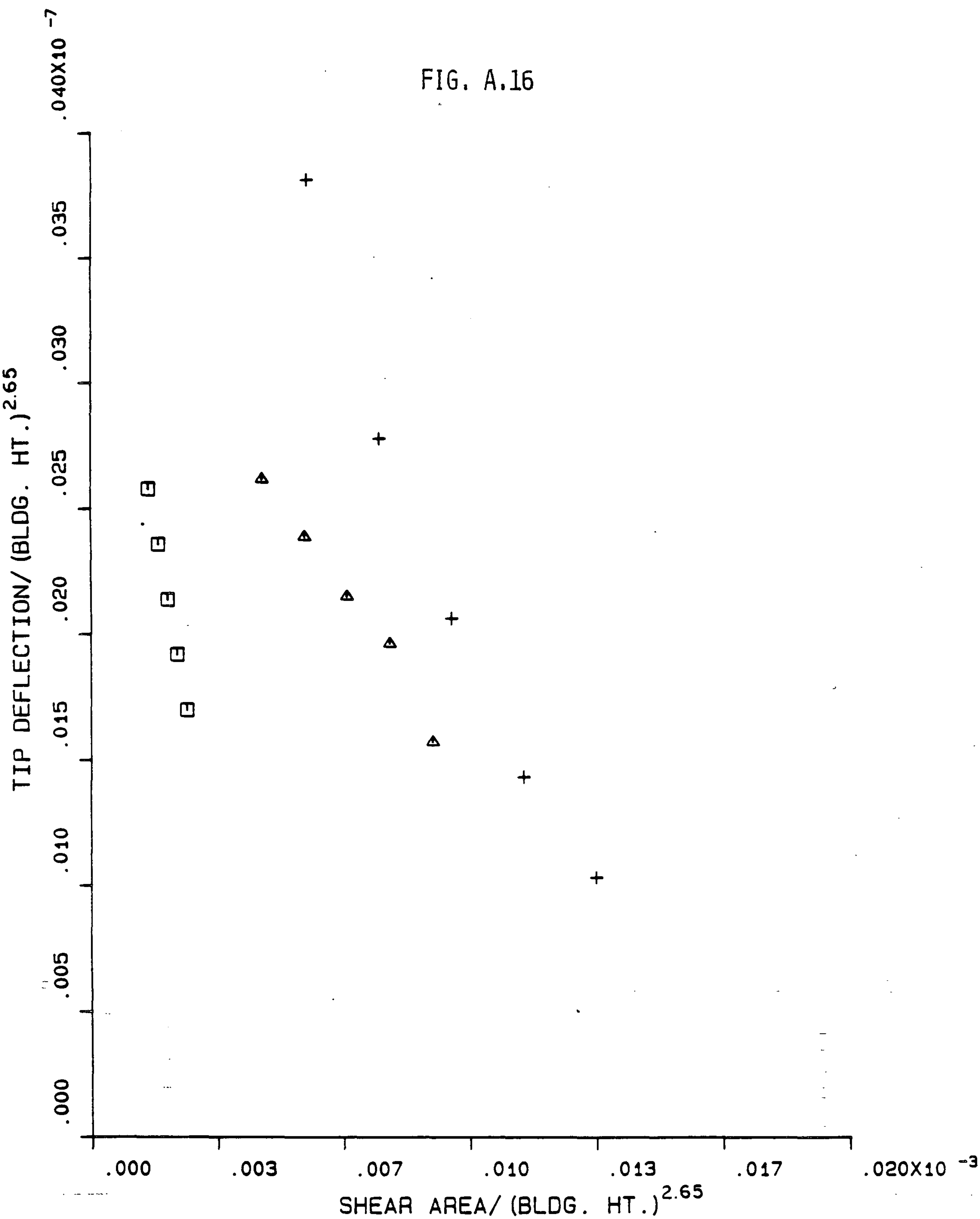
SCATTER DIAGRAM

FIG. A.15



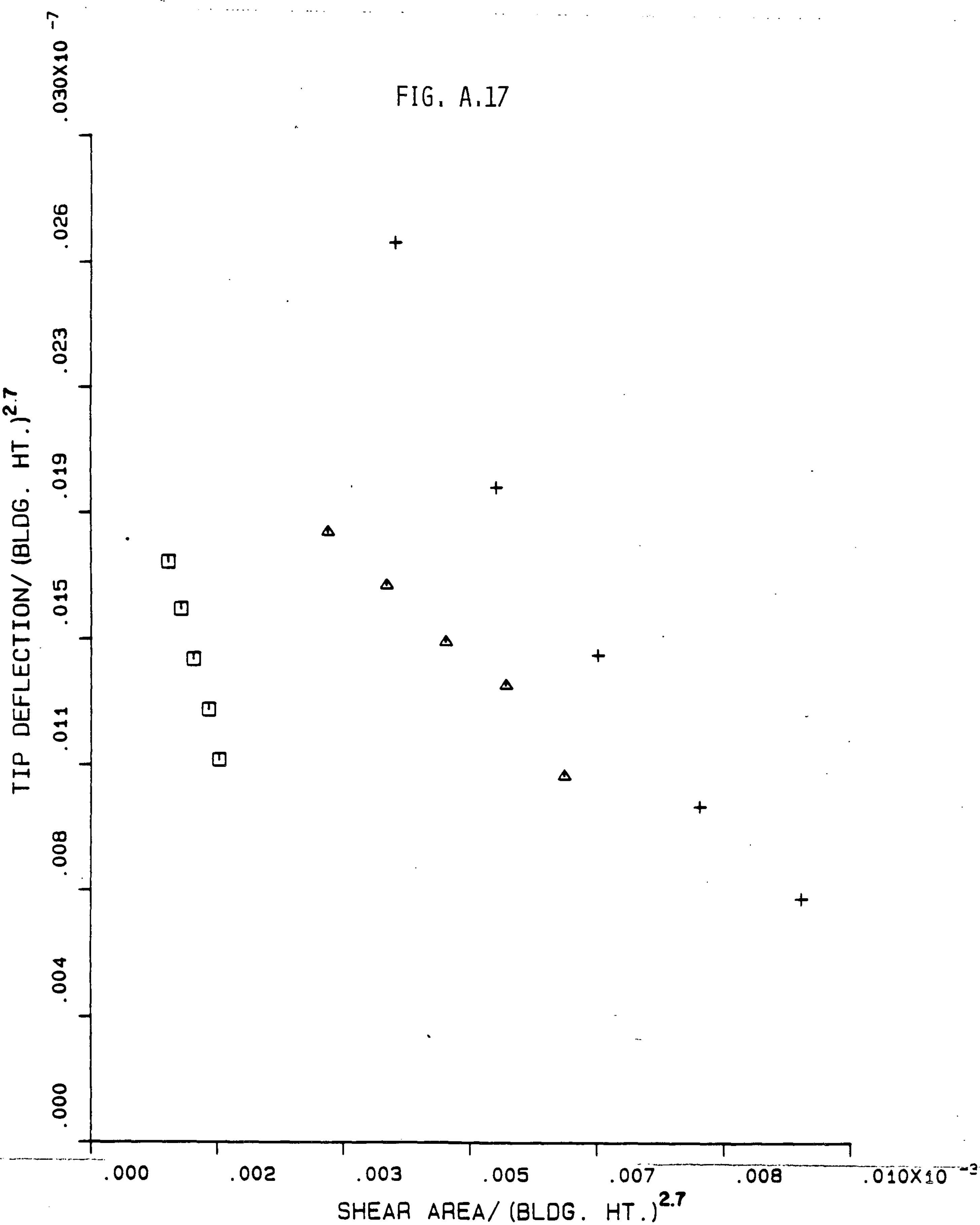
SCATTER DIAGRAM

FIG. A.16



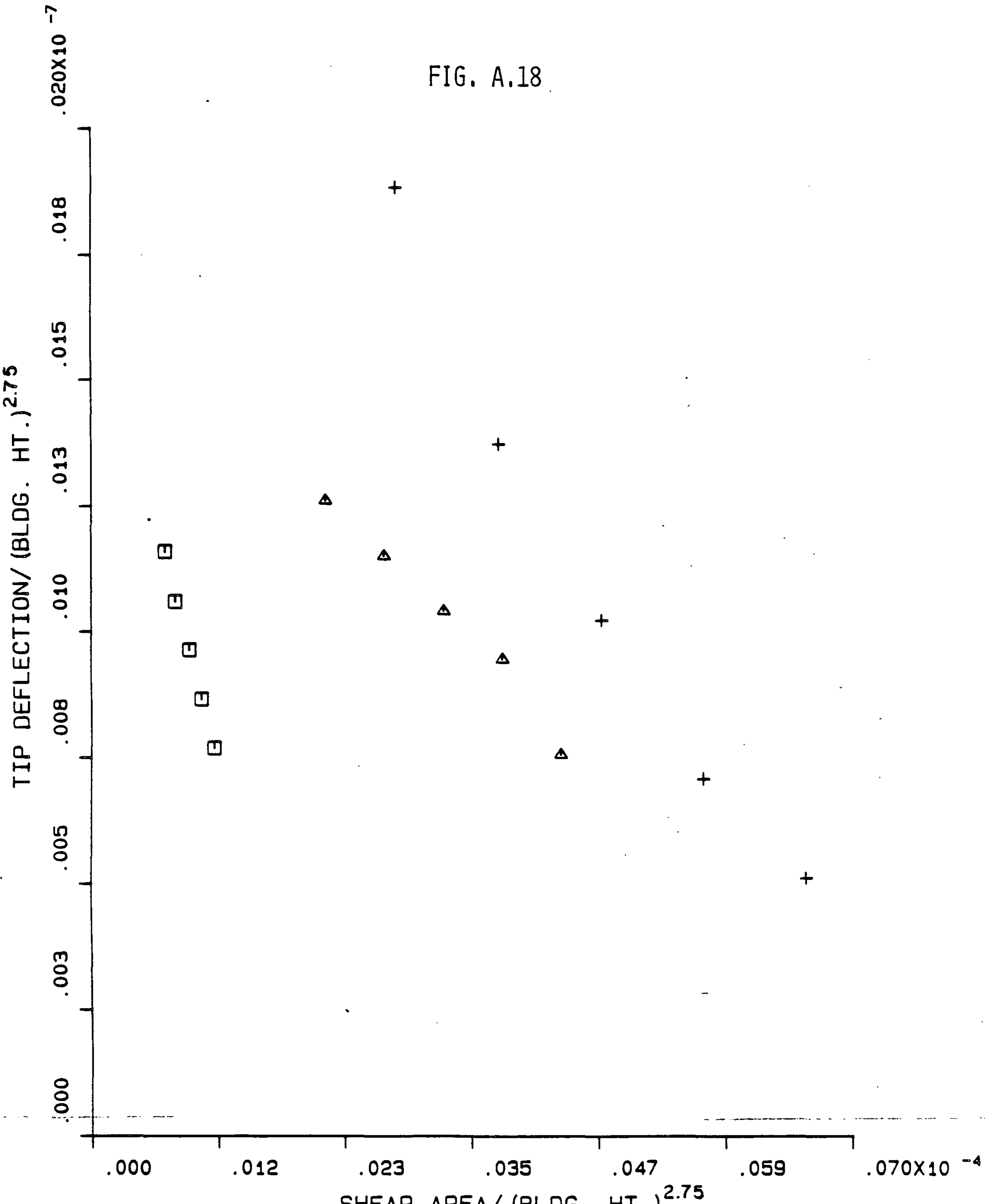
SCATTER DIAGRAM

FIG. A.17



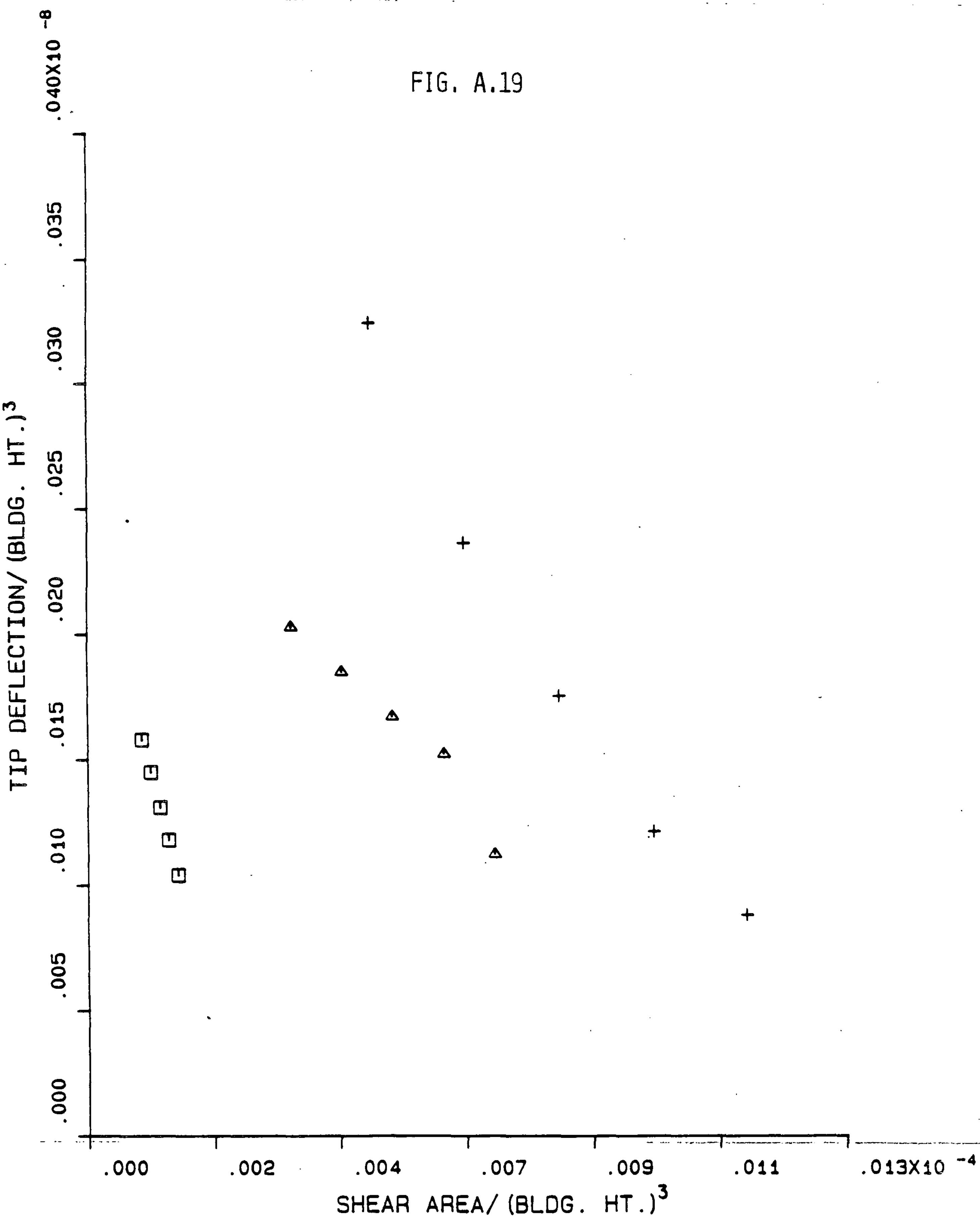
SCATTER DIAGRAM

FIG. A.18



SCATTER DIAGRAM

FIG. A.19



SCATTER DIAGRAM

APPENDIX B

SINGLE VARIABLE REGRESSION ANALYSIS

Presented are test statistics from the BMDP statistical software package polynomial regression program. These values are used to evaluate the regression model.

The two statistics presented are the standard error value and the T-statistic for each coefficient of each degree polynomial. The T-statistic is basically used to construct a confidence interval for each regression coefficient (B's).

The standard error value is used as an estimator for the standard deviation from which confidence and prediction intervals can be obtained.

Results from polynomials of degree one through nine are presented.

TABLE B.1

POLYNOMIAL REGRESSION STATISTICS			
DEGREE OF POLYNOMIAL		ONE	
	COEFFICIENTS	STANDARD ERROR	T - STATISTIC
B_0	.49780E-06	.18374E-07	29.09
B_1	-.31252E-02	.24427E-04	-12.79

TABLE B.2

POLYNOMIAL REGRESSION STATISTICS			
DEGREE OF POLYNOMIAL		TWO	
COEFFICIENTS		STANDARD ERROR	T - STATISTIC
B_0	.53554E-06	.44219E-07	12.11
B_1	-.43467E-03	.13237E-03	-3.28
B_2	.81891E-01	.87205E-01	.94

TABLE B.3

POLYNOMIAL REGRESSION STATISTICS			
DEGREE OF POLYNOMIAL		THREE	
COEFFICIENTS		STANDARD ERROR	T - STATISTIC
B_0	.68979E-06	.10327E-06	6.68
B_1	-.11949E-02	.48245E-03	-2.48
B_2	.11694E+01	.67190	1.74
B_3	-.46756E+03	.28674E+03	-1.63

TABLE B.4

POLYNOMIAL REGRESSION STATISTICS			
DEGREE OF POLYNOMIAL		FOUR	
COEFFICIENTS		STANDARD ERROR	T - STATISTIC
B_0	.10498E-05	.25261E-06	4.16
B_1	-.36190E-02	.16343E-02	-2.21
B_2	.66963E+01	.36346E+01	1.84
B_3	-.55910E+04	.3328E+04	-1.68
B_4	.16525E+07	.10701E+07	1.54

TABLE B.5

POLYNOMIAL REGRESSION STATISTICS			
DEGREE OF POLYNOMIAL		FIVE	
COEFFICIENTS		STANDARD ERROR	T - STATISTIC
B_0	.15861E-05	.71814E-06	2.21
B_1	-.82074E-02	.59724E-02	-1.37
B_2	.21199E+02	.18503E+02	1.15
B_3	-.26891E+05	.26843E+05	1.00
B_4	.16318E+08	.18366E+08	.89
B_5	-.38181E+10	.47729E+10	-.80

TABLE B.6

POLYNOMIAL REGRESSION STATISTICS			
DEGREE OF POLYNOMIAL		SIX	
COEFFICIENTS		STANDARD ERROR	T - STATISTIC
B_0	.27193E-05	.21147E-05	1.29
B_1	-.19985E-01	.21480E-01	-.93
B_2	.69092E+02	.85802E+02	.81
B_3	-.12474E+06	.17311E+06	-.72
B_4	.12277E+09	.18684E+09	.66
B_5	-.62589E+11	.10273E+12	-.61
B_6	.12928E+14	.22571E+14	.57

TABLE B.7

POLYNOMIAL REGRESSION STATISTICS			
DEGREE OF POLYNOMIAL		SEVEN	
	COEFFICIENTS	STANDARD ERROR	T - STATISTIC
B_0	-.65977E-05	.60878E-05	-1.08
B_1	.94495E-01	.73603E-01	1.28
B_2	-.50342E+03	.36333E+03	-1.39
B_3	.13883E+07	.95088E+06	1.46
B_4	-.21658E+10	.14285E+10	-1.52
B_5	.19251E+13	.12353E+13	1.56
B_6	-.90804E+15	.5711E+15	-1.59
B_7	.176206E+18	.10920E+18	1.61

TABLE B.8

POLYNOMIAL REGRESSION STATISTICS			
DEGREE OF POLYNOMIAL		EIGHT	
COEFFICIENTS		STANDARD ERROR	T - STATISTIC
B_0	-.13949E-04	.1736E-04	-.80
B_1	.19749	.23891	.83
B_2	-.11080E+04	.13803E+04	-.80
B_3	.33333E+07	.43811E+07	.76
B_4	-.59234E+10	.83749E+10	-.71
B_5	.63998E+13	.98958E+13	.65
B_6	-.41235E+16	.70741E+16	-.58
B_7	.14539E+19	.28029E+19	.52
B_8	-.21542E+21	.47218E+21	-.46

TABLE B.9

POLYNOMIAL REGRESSION STATISTICS			
DEGREE OF POLYNOMIAL		NINE	
COEFFICIENTS		STANDARD ERROR	T - STATISTIC
B_0	-.37375E-04	.66614E-04	-.56
B_1	.56896	.10459E+01	.54
B_2	-.36292E+04	.70387E+04	-.52
B_3	.12952E+08	.26668E+08	.49
B_4	-.28683E+11	.62744E+11	-.46
B_5	.41089E+14	.95248E+14	.43
B_6	-.38238E+17	.93393E+17	-.41
B_7	.22369E+20	.57145E+20	.39
B_8	-.748247E+22	.19834E+23	-.38
B_9	.10923E+25	.29803E+25	.37

APPENDIX C

MULTI-VARIABLE REGRESSION ANALYSIS

The regression program developed for this study utilizes coordinate function expressions to define each variable (Ref. 27). The following paragraphs will describe in more detail the theory and methodology employed to develop the program used.

In multi-variable regression analysis, there is usually more than one independent variable associated with the problem. Usually interest is focused on the effect of just one variable while keeping all others constant. The assembly of the k_{ij} terms of the series for this one variable (j-th variable) is called the coordinate function F_j. The coordinate function's individual terms are selected to make a close approximation to the given data points for various sets of the other variables. The purpose of this step is to utilize as few terms as possible for an acceptable fit. The coordinate function F_j for the j-th variable contains n_j terms as seen in Equation (C.1).

$$F_j = [\ k_{ji},\ k_{j2} \ldots\ldots k_j\ n_j] \tag{C.1}$$

With coordinate functions established for each variable, the terms of the final series are shown in Equation (C.2). The equation contains products of the terms of the individual coordinate functions.

$$S = \Sigma B_j f_j = \{B_j\}^T\ [f_1 f_2 \ldots . f_n]^T = B^T\ [f_1 f_2 \ldots . f_n] \tag{C.2}$$

The final coordinate function is obtained as a direct product of the terms. Since no true mathematical representation for this operation exists, this process shall be signified by the following designation dprod (......). Thus, a change in the coordinate function of a particular variable does not affect the coordinate functions of the other variables. Finally, the unknown coefficients $\{B_i\}$ are found by solution of a set of simultaneous equations as given by Equation (C.3).

$$W \{ B \} = R \tag{C.3}$$

Where $W = U^T U$ and $R = U^T H$

B - Column Vector of Unknown Coefficients
H - Column Vector of Approximations of Function Values.

$U = [f_{ji}]_{m \times n}$ - Rectangular matrix where each row contains the values of the individual functions of the series for a particular point that is, for a particular value of the independent variable.

Equation (C.4) shows the coordinate function obtained as the direct product of the terms.

$$F = [f_1 \; f2 \ldots . f_n] = \text{dprod } (F_1 \;\; F_2 \ldots F_n)$$

$$F = [(k_{11}, k_{21} \ldots k_{ji} \; (k_{12}, k_{22} \ldots k_{j2}) \ldots (k_{1nj}, k_{2nj} \ldots k_{jnj})]. \tag{C.4}$$

To illustrate Equation (C.4), an example utilizing two variables X_1

and X_2 is carried out. Assume each coordinte function to have the following number of terms where $n_1 = 2$ and $n_2 = 3$. The functions are illustrated as follows:

$$F_1 = [k_{11}\ k_{12}] \quad \text{insert variable} \quad F_1\ [X_1\ X_1^4] \tag{C.5}$$

$$F_2 = [k_{21}\ k_{22}\ k_{23}] \quad \text{insert variable} \quad F_2 = [X_2^4\ \ 2\ \ X_2^3] \tag{C.6}$$

The expanded function F becomes a matrix containing the products of the terms of these individual coordinate function with the total number of terms n being as follows:

$$n = 2 \times 3 = 6$$

therefore,

$$F = \text{dprod}\ (F_1\ F_2)$$

$$F = [k_{11}k_{21}\quad k_{12}k_{21}\quad k_{11}k_{22}\quad k_{12}k_{22}\quad k_{11}\quad k_{23}\quad k_{12}k_{23}]$$

$$F = [X_1X_2^4\quad X_1^4X_2^4\quad X_12\quad X_1^42\quad X_1X_2^3\quad X_1^4X_2^3] \tag{C.7}$$

If a third variable is introduced i.e., $n_3 = 2$, then the number of terms in the function F will be:

$$n = (n_1 = 2)\ (n_2 = 3)\ (n_3 = 2) = 12 \tag{C.8}$$

For a particular point, the expanded function equation (C.7) gives one row of the U matrix equation (C.3). The number of rows of U r (which is also the number of points must be at least equal to the number of columns, c, in order to have a solution of equation (C.3) for the unknown coefficients $B = \{b_i\}$.

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